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MEDICAL CONSEQUENCES OF NUCLEAR WARFARE

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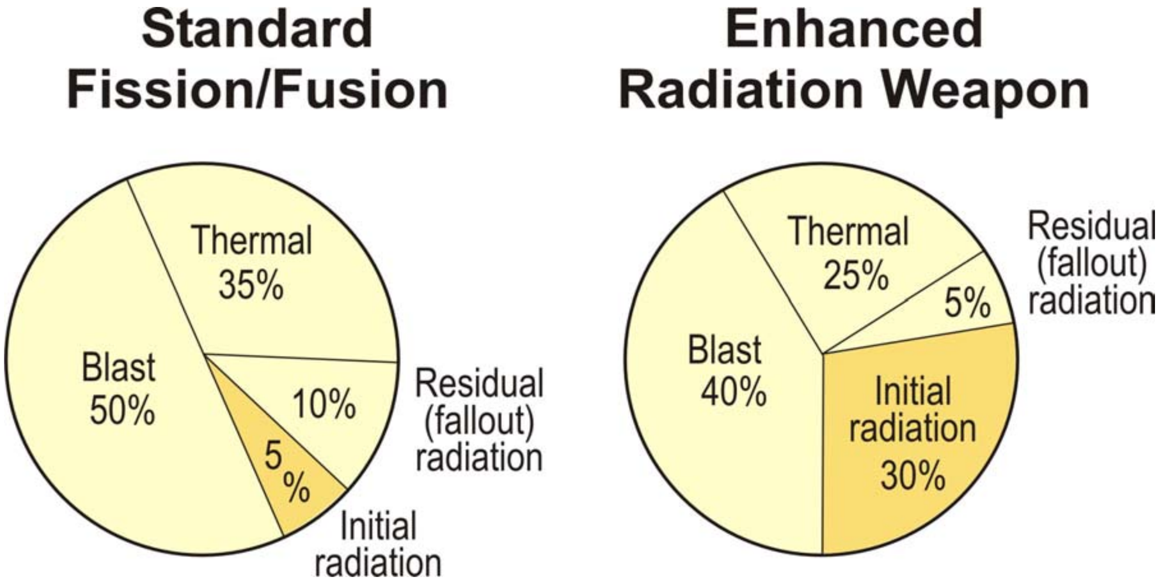

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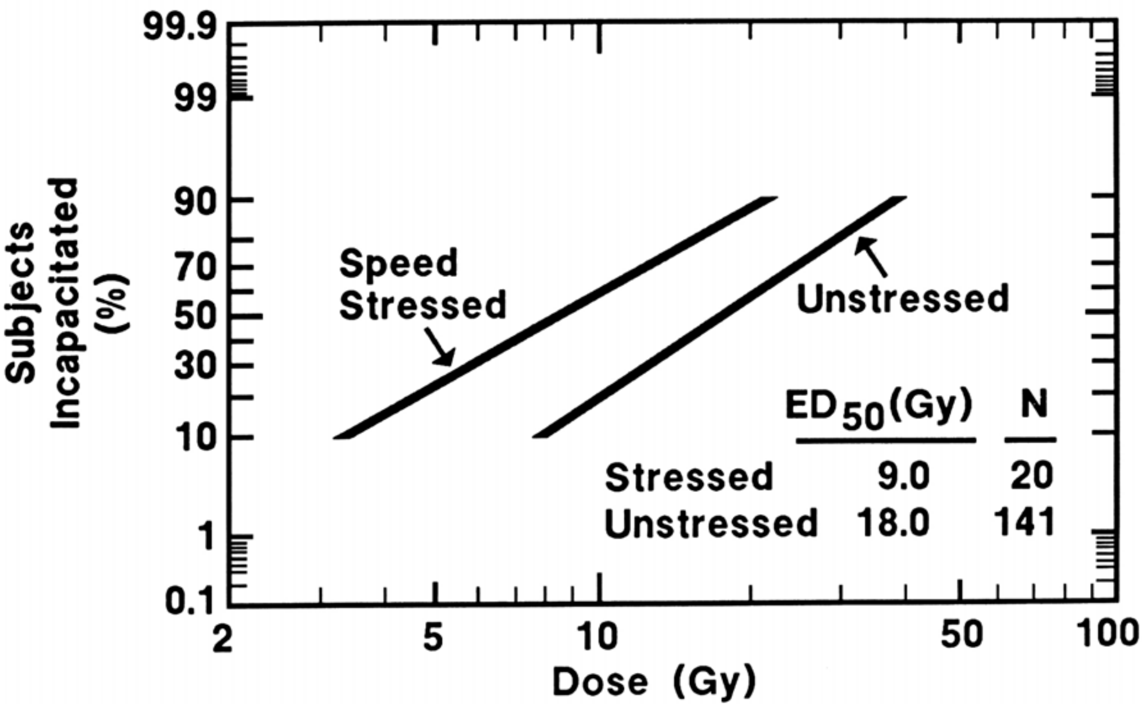

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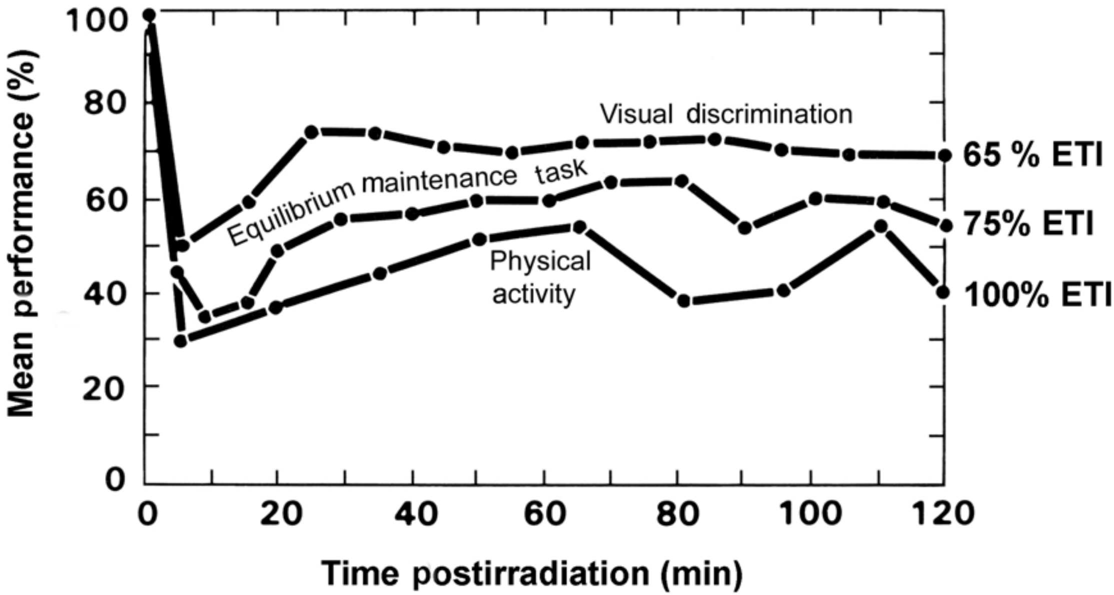

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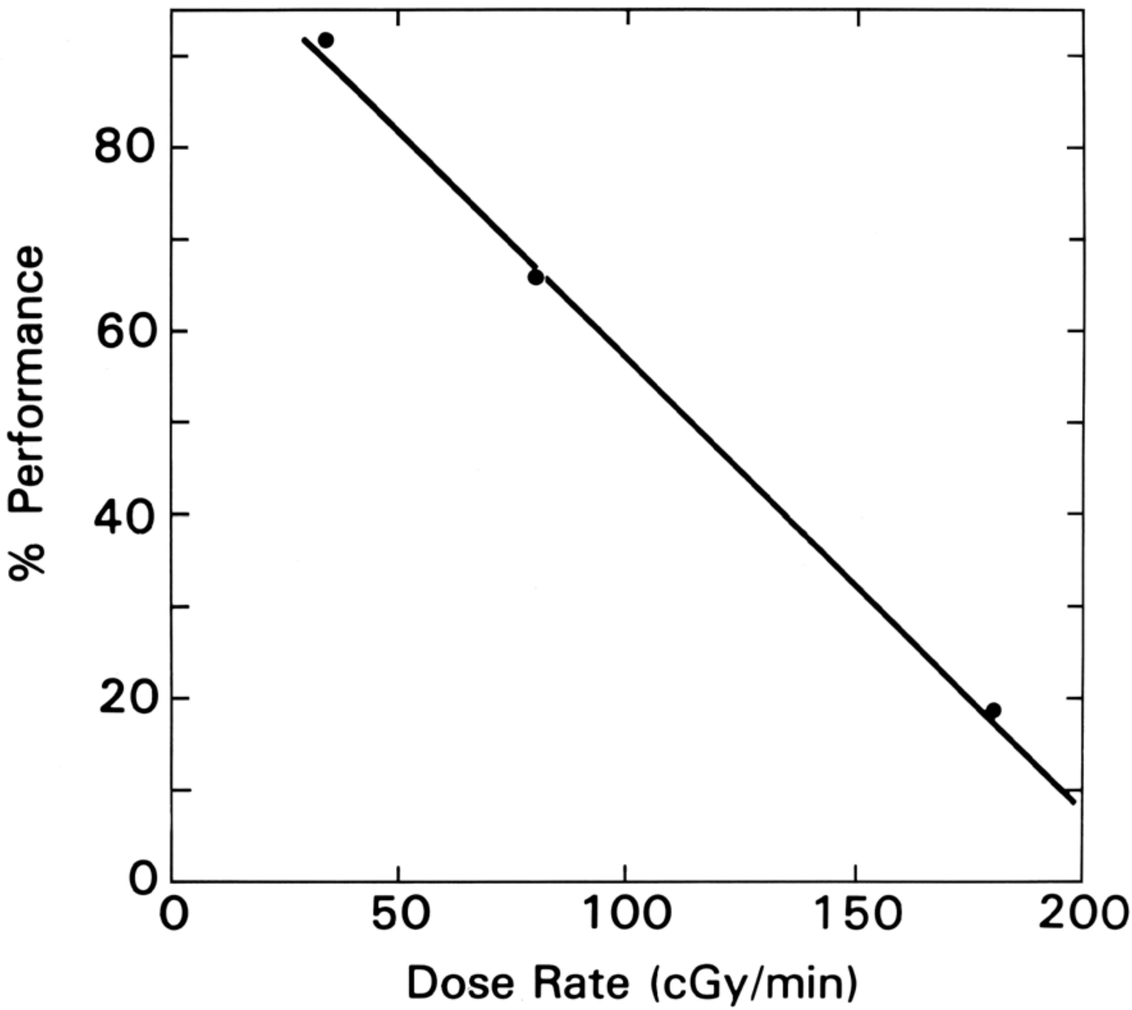

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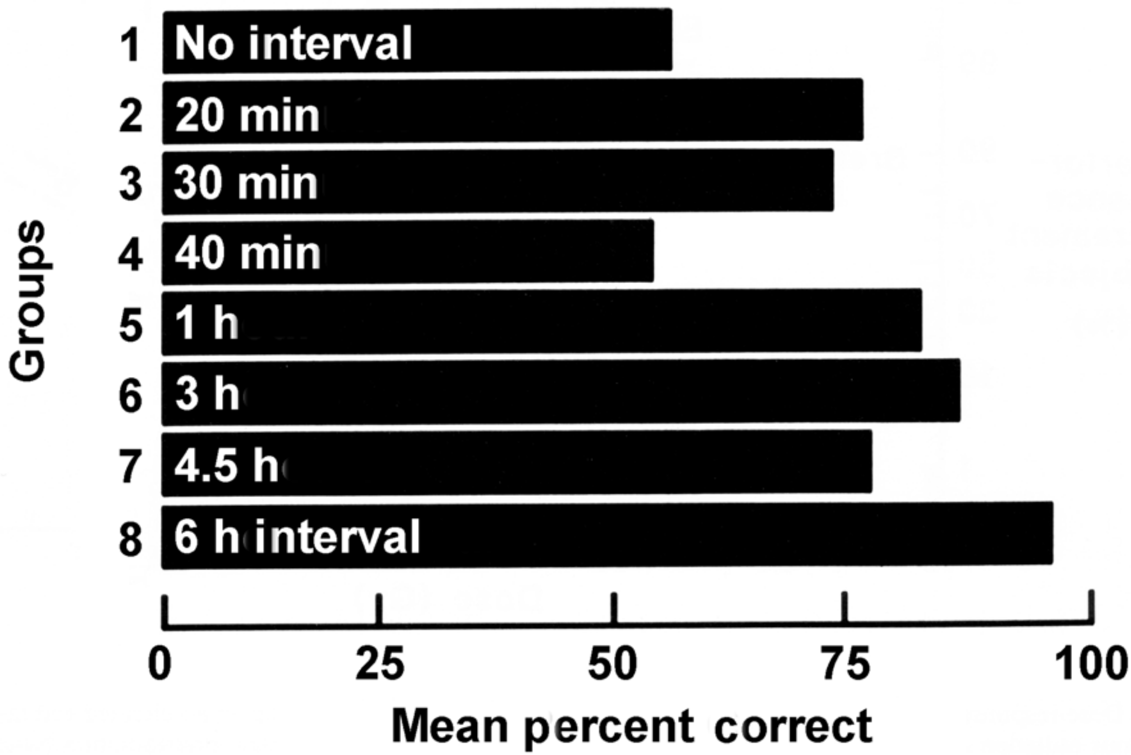

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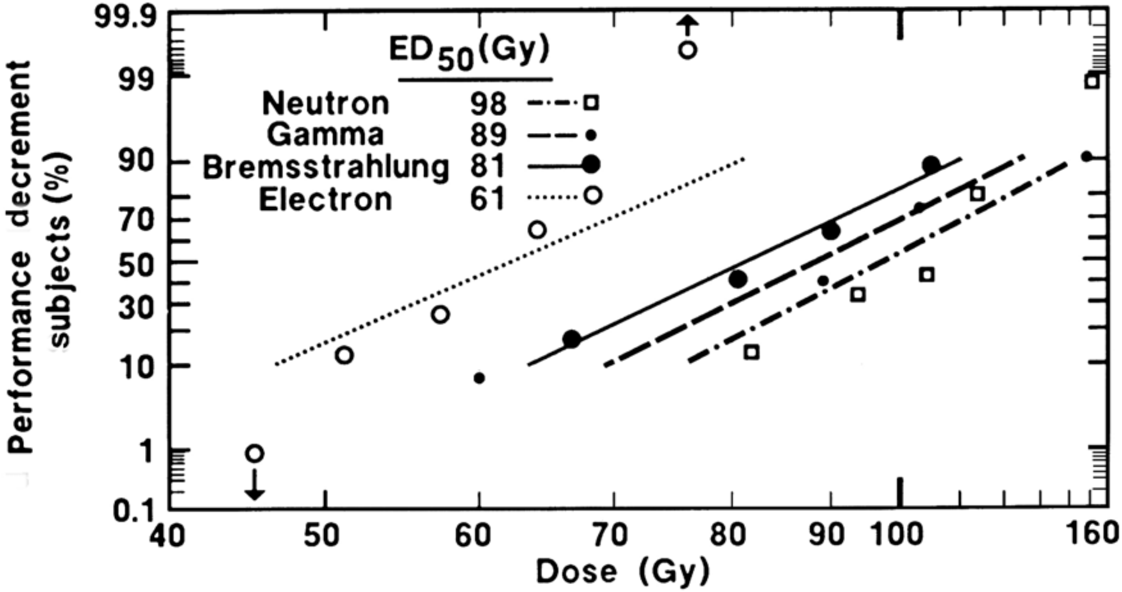

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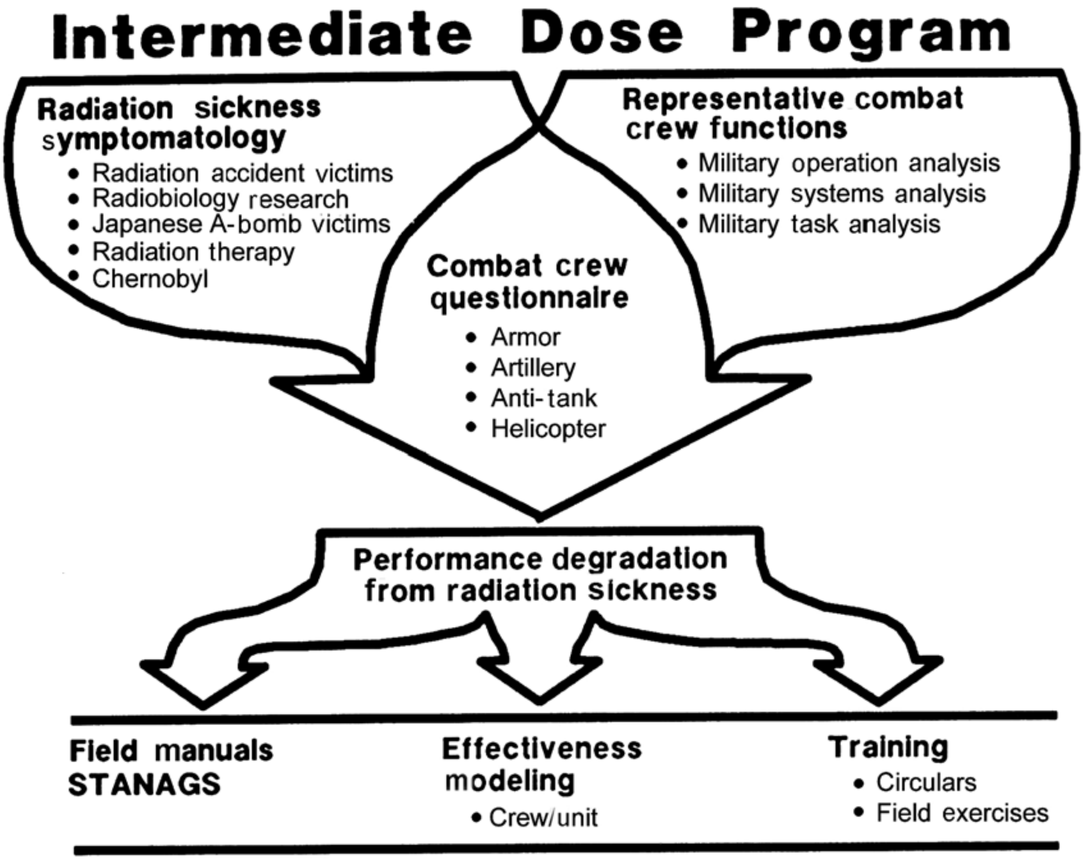

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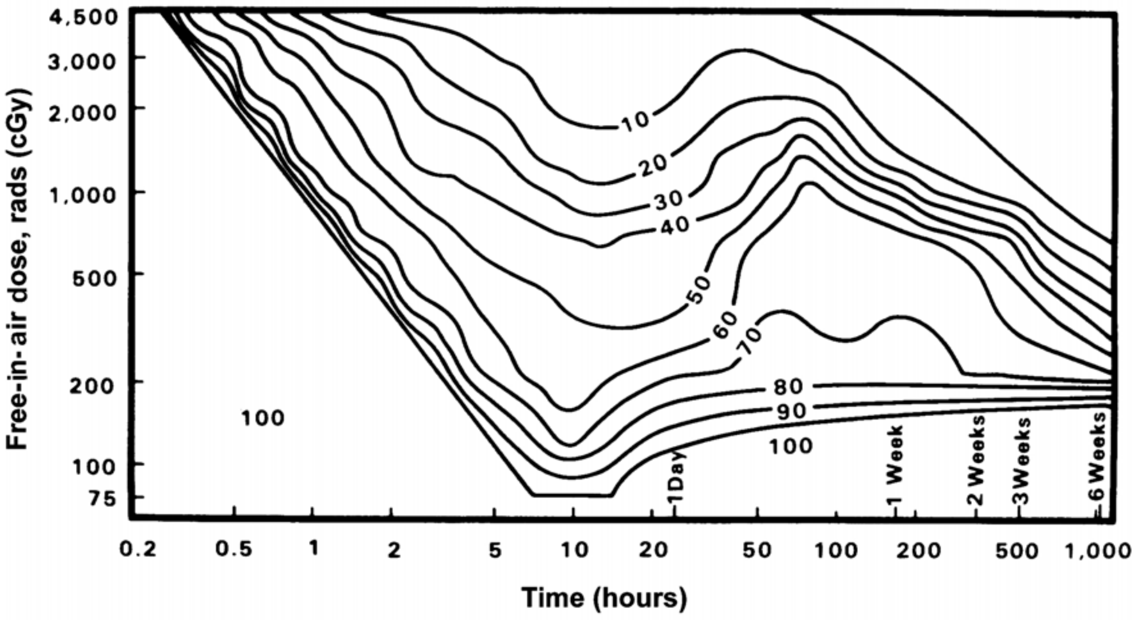

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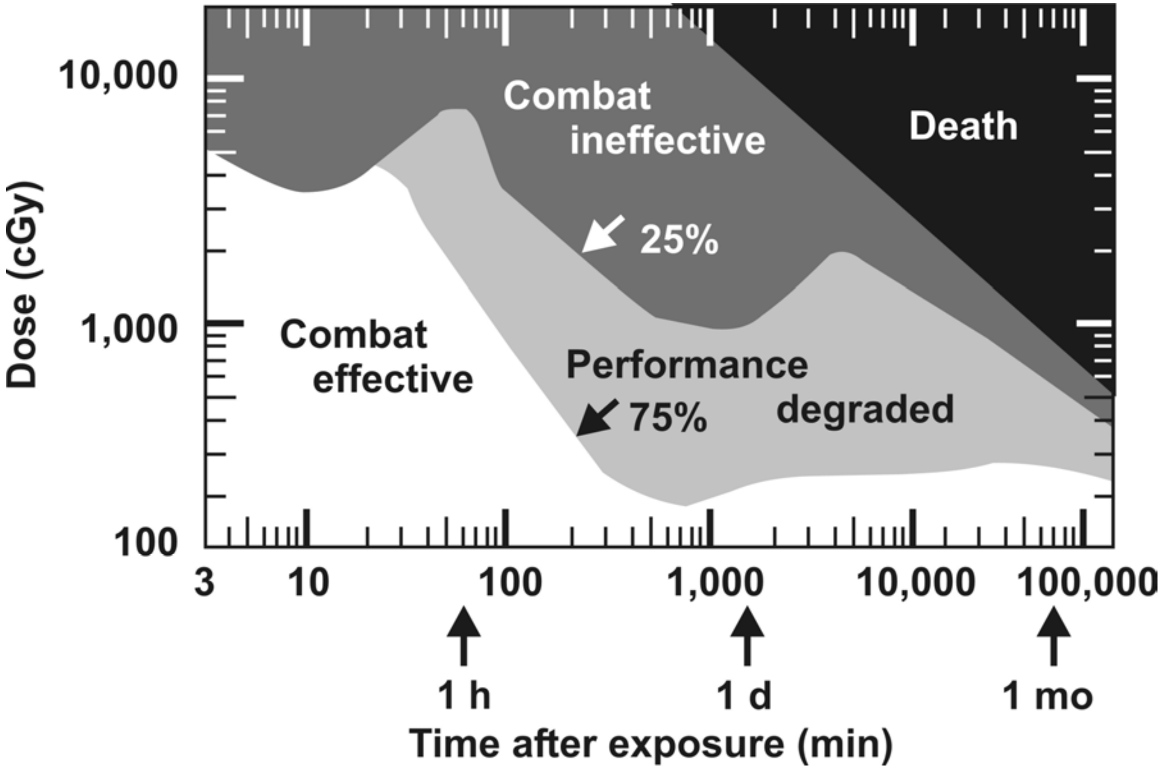

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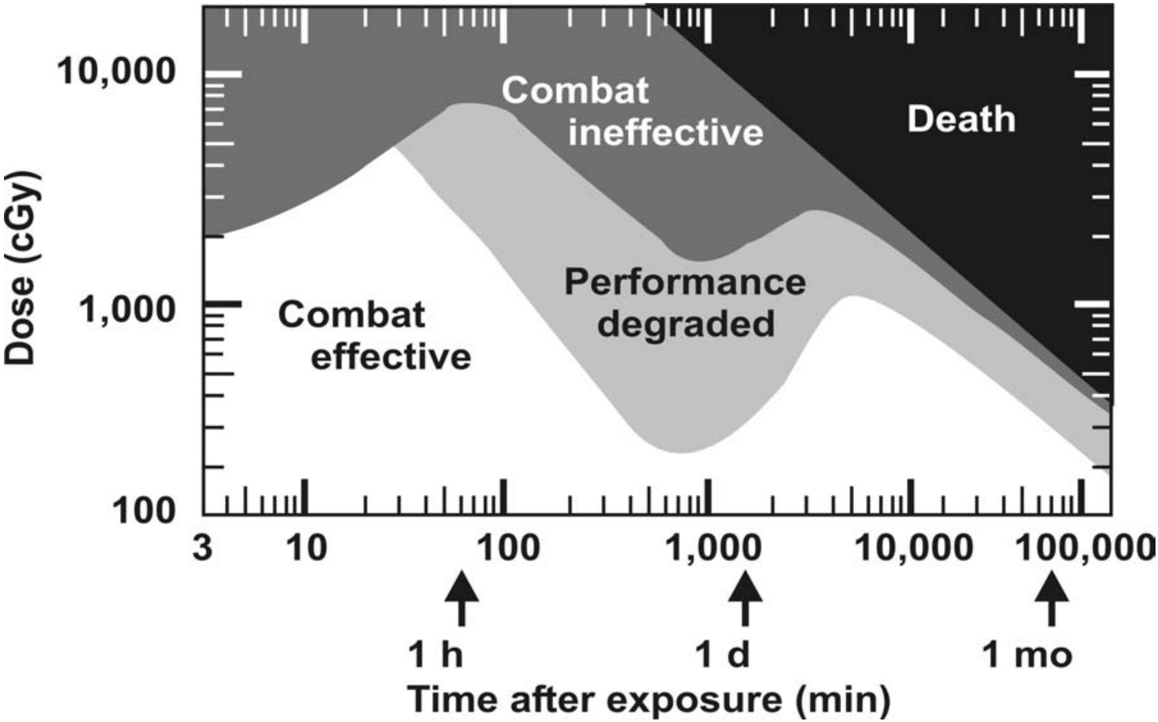

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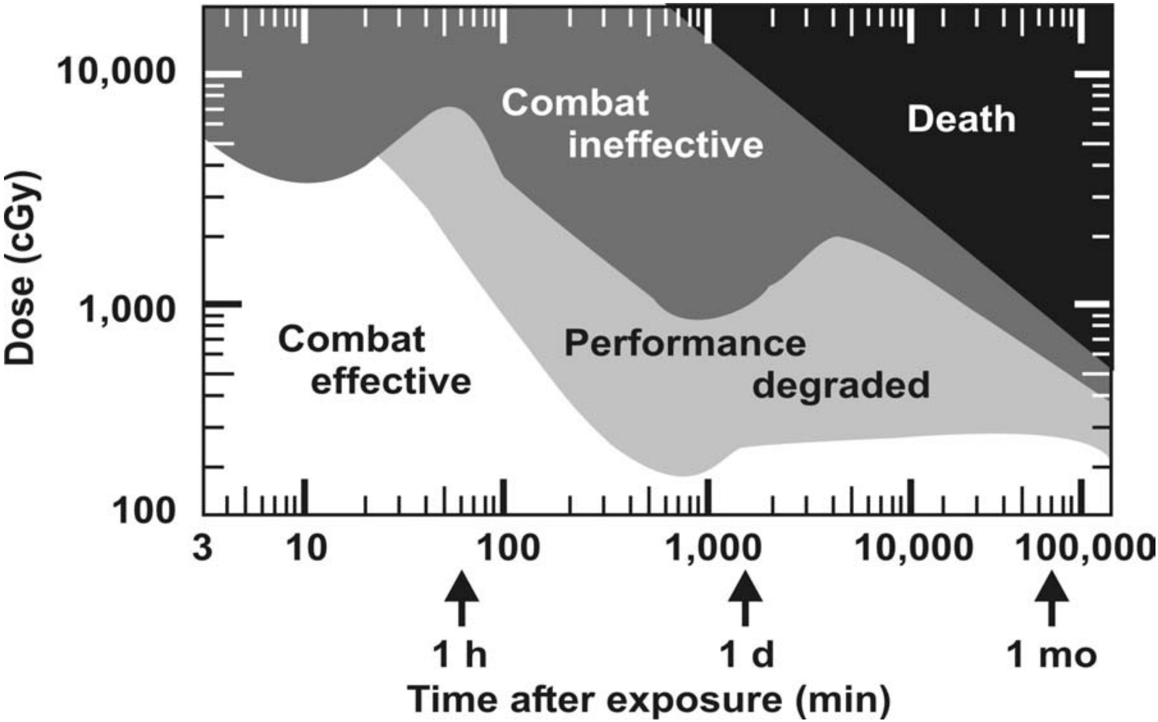

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TABLE 7-1
RADIATION-INDUCED EARLY TRANSIENT INCAPACITATION (ETI) AS A FUNCTION OF TASK COMPLEXITY OR TASK DIFFICULTY

Rank Order of Task Difficulty*	Task or Behavioral Criterion	Dose to Produce ETI (Gy)	Reference
1	Observation	50-300	110,115
2	Continuous avoidance **	50-100	116
3	Visual-discrimination task***	22	117,118
4	Speed-stress visual-discrimination task†	9††	44

* Ranked from least to most difficult or complex

** Presentation of light required monkey to press a lever every 20 seconds to avoid shock

*** Circle and square randomly presented every 10 seconds on two backlit press-plates. Subject had 5 seconds to touch the square to avoid shock.

† Subject had 0.7 seconds to avoid shock

†† Calculated ED50 = median effective dose. Other numbers in this column were empirically observed instances of ETI and were not derived from curved fitting.

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TABLE 7-2
MEDIAN EFFECTIVE DOSES REQUIRED TO ACHIEVE DIFFERENT BEHAVIORAL END POINTS IN IRRADIATED MONKEYS

Task	End Point	ED_{50} (Gy)	Reference
Speed-stress visual-discrimination task*	Early transient Incapacitation (ETI)**	9	44
Speed-stress visual-discrimination task	Early performance decrement (EPD)***	7	44
Delayed match-to sample task	EPD+	3-5	111

* Response time 0.7 seconds or less
** Defined as six consecutive omissions or 1 minute of nonperformance
*** EPD defined as 2 z-scores below baseline performance levels

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Chapter 8

PSYCHOLOGICAL FACTORS IN NUCLEAR WARFARE

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INTRODUCTION

The psychological casualties of a nuclear conflict may seem to be insignificant compared to the casualties from physical trauma, but they can dramatically alter the outcome of a battle. The neuropsychiatric casualties of World War Il were 18%-48% of all casualties,[1,2] and they were the largest single cause of lost military personnel strength in that war.[3] The Arab-Israeli Yom Kippur War of 1973 lasted only 3 weeks, but its psychiatric casualties were 23% of all nonfatal casualties.[4] Even if neuropsychiatric trauma from intense combat does not produce a casualty, it can degrade the performance of normal duties. Slightly altered reaction times, attention, or motives may have important consequences in warfare.

DETERMINANTS OF PSYCHOLOGICAL DYSFUNCTION IN CONVENTIONAL WARFARE

Much has been learned about the origins of psychiatric casualties of war. On the most basic level, even visual representations of war evoke significant increases in sympathetic activity as indicated by increased electrodermal activity, decreased salivary function, and marked cardiac changes.[5] These changes in physiology are correlated with higher scores on psychological measures of stress. However, laboratory measurements significantly oversimplify the array of variables that co-produce a particular behavioral and psychological outcome. These variables include the intensity and duration of the battle, the leadership and cohesiveness of the group, the availability of information and ability or inability to communicate it, physical strain, individual expectations, experience, and morale.

Intensity of the Battle

The most important precipitating factor affecting the rate of neuropsychiatric casualties is the battle's intensity or the current degree of stress.[2,6] Combat is usually episodic, but the effect of combat stress is often cumulative. An analysis of three infantry battalions in the Sicilian campaign of World War II revealed that the number of casualties from physical wounds remained relatively constant over the 17 days studied, but the number of psychiatric casualties steadily increased.[2]

Group Characteristics

Morale, group leadership, and cohesiveness are also good predictors of neuropsychiatric casualties.[1] In a study completed after the 1973 Yom Kippur War, the Israelis revealed that 40% of the soldiers with battle shock reported minimal group cohesion and unit identification, as well as a high incidence of interpersonal difficulties with members of their units. In contrast, only 10% of the soldiers not suffering battle shock reported these unit problems.[4] Psychologically impaired persons were also more likely to have changed teams in combat (63%) than were the control population who experienced no psychological difficulties (15%).[7]

These data suggest that strong, stable groups play an important role in preserving the individual's psychological stability in combat.

Duration of the Battle

Expectations about the duration of hostilities affect the psychiatric casualty rate. A decided decrease in neuropsychiatric casualties occurred in the European theater of World War II toward the end of hostilities in 1945. Conversely, the low psychiatric casualty rate of the British soldiers has been attributed, in part, to the British policy of long tours of duty. Believing there was little chance of relief, the soldiers knew that they would have to hold on.[2]

Physical Strain

The terms “combat fatigue” and “combat exhaustion,” widely used in the past, indicated that a lack of sleep, lack of food, and other fatiguing properties of combat played an important role in psychiatric breakdown. This impression was supported when psychological symptoms were often partially relieved by sleep and food. Although this suggested that physical fatigue precipitates psychiatric illness, it is now clear that fatigue itself is not the primary cause of psychiatric breakdown. Units advancing against slight enemy opposition may continue without sleep or food for several days, and although the unit members may suffer physical fatigue, they rarely show psychiatric symptoms. A low incidence of psychiatric casualties is also associated with long retreats.[2] Finally, typical psychiatric symptoms may appear early in combat or even prior to battle, before the occurrence of appreciable physical fatigue.[8-10]

Consequences of Incapacitation

Neuropsychiatric casualty rates in wartime tend to be low when the soldier perceives that becoming a casualty either causes additional harm or produces no important advantage. This was the case during the German retreat at Stalingrad when the fleeing Germans feared capture by the Russians. Neuropsychiatric casualties frequently occur after rather than during a battle, when the fate of an incapacitated person is uncertain.[2]

Expectations of the Culture

Expectations of the group or the culture may also influence psychiatric casualty rates. The incidence of psychiatric casualties was low in both the American and South Vietnamese armies during the Vietnam War, but the total number of cases admitted (during a 6-month period) to U.S. hospitals was almost double the number admitted to South Vietnamese hospitals, despite the fact that the total population at risk was considerably larger for the South Vietnamese. Some authors have attributed this to the constraints on some psychiatric diagnoses in the Vietnamese culture.[11]

A similar situation occurred in the Korean War. Early in the war, when most Republic of Korea troops and their officers were relatively untrained and new to combat, it was expected that psychiatric casualties would be high. However, this was not the case, because such behavior was not culturally acceptable. Later in the war, when Korean soldiers were integrated into American units, they incurred psychiatric breakdowns with the same frequency and symptoms as their American comrades.[10]

Finally, anxiety states were far less common in Indian soldiers than in British soldiers fighting side by side during the Arakan campaign in Burma in 1943-1944. The Indian soldiers may have felt as anxious as their British comrades, but they could not admit it; their culture dictated that they enjoy battle, and it was a point of honor to do so. The Indian soldier could deal with anxiety only by denying its existence, by using a magical charm, or by self-inflicting a wound (which released him with honor intact). If these methods were not feasible, the Indian soldier might break into exuberant hysterical behavior similar to the accepted religious displays of his culture; this released tension and entailed no social stigma.[3]

Communication

The way in which soldiers respond in any situation depends on how they perceive it; how they perceive it depends on the information they have about it. A person who is uninformed in a complex, chaotic situation will be under great stress. Disruption of communications during warfare may produce sufficient anxiety and fear to degrade performance.[2] Reduced communication can also impose significant psychological stress in a nuclear conflict.[12]

NUCLEAR WARFARE VERSUS CONVENTIONAL WARFARE

The debate continues over the expected differences between the psychological changes produced by conventional war and those produced by nuclear war. Experts at a recent symposium on the psychological effects of tactical nuclear warfare agreed that differences would exist, but there was considerable disagreement over whether the differences would be quantitative, qualitative, or both. With a quantitative difference, more combatants would experience higher levels of fear, stress, and confusion, resulting in a greater number of neuropsychiatric casualties. However, if the differences are qualitative, the soldiers might experience completely different psychological symptoms, and a new and different response to the stress of war might emerge.[13]

Nuclear weapons have the power to produce such devastation that the apparent unreality of the detonation's aftermath may differentiate a nuclear battle from a conventional battle. A modern warhead can produce an explosion measured in

megatons. Two megatons is roughly equal to the explosive output of all bombs dropped during World War II.[14] A Japanese survivor of the nuclear detonation at Hiroshima described a scene illustrative of the severity of the nuclear battlefield:

> I had to cross the river to reach the station. As I came to the river and went down the bank to the water, I found that the stream was filled with dead bodies. I started to cross by crawling over the corpses, on my hands and knees. As I got about a third of the way across, a dead body began to sink under my weight and I went into the water, wetting my burned skin. It pained severely. I could go no further, as there was a break in the bridge of corpses, so I turned back to the shore, and started to walk upstream, hoping to come upon another way across.[15]

Both nuclear and conventional weapons produce blast and thermal effects, but ionizing radiations are unique to nuclear weapons. Radiation effects may have caused as many as 15%-20% of the deaths at Hiroshima and Nagasaki.[16] The insidious and lethal nature of radiation makes it especially feared. In 1951, Brigadier General James Cooney worried about his soldiers' ability to function in a nuclear battle, because radiation associated with the atomic bomb was believed by many to "cause immediate and mysterious injury or death."[17] Despite our current knowledge about radiation effects, these beliefs are still pervasive. The 1979 nuclear reactor accident at Three Mile Island produced almost no radiation exposure above normal background levels, but the public believed that a radiation hazard was present, which evoked long-term signs of emotional, behavioral, and physiological stress.[18]

The psychological reactions to nuclear warfare have an added dimension, namely, anxiety that the human species will be annihilated. People achieve symbolic immortality by identifying with their children, grandchildren, and larger cultural units, such as their nation or religion.[19] Unlike all the past wars, in a strategic nuclear war we will not be able to sacrifice ourselves so that our children, family, or nation can survive. This loss of assurance of a future for humanity may result in emotional changes that differ from those during a conventional war.[20]

The psychological changes in persons exposed to nuclear weapons will partially coincide with those seen in other disasters. But the magnitude and type of destruction from a nuclear weapon will probably (at least) intensify most psychological reactions. By 1945, the people of Japan were accustomed to destruction from conventional bombing. However, the atomic bomb effects were new and vastly more horrible, eliciting more extreme psychological reactions in the residents of Hiroshima and Nagasaki who responded to the U.S. Strategic Bombing Survey several years later.[21] Still debatable is the question of qualitative differences in the psychological responses to different types of natural disasters and other stressful events. Psychological symptom complexes may differ, depending on the nature of the disaster.[22] In some studies, the psychological morbidity is clearly defined by

diagnostic criteria, such as those identified for post-traumatic stress disorder, anxiety, or depression. Other studies address a more nonspecific psychological distress reaction. Symptom clusters and perhaps specific somatic complaints may be specifically related to particular types of disasters.[22] It would not be surprising if in-depth studies reveal that some components of stress reactions are more likely to be expressed during nuclear conflicts than during conventional warfare or natural disasters.[1,23,24]

PSYCHOLOGY IN TODAY'S NUCLEAR MILIEU

When a person is faced with the horror of nuclear warfare, the responses are fairly predictable: fear, dread, and finally denial. It has been suggested that the levels of fear and anxiety in the world's population have been substantially increased by the prospect of nuclear annihilation. In 1984, Gallup surveyed 514 teenagers (ages 13-18), as a representative national cross section, on the likelihood of the occurrence of nuclear confrontations in their lifetimes.[25] Fifty-one percent indicated that it was “somewhat likely” that a nuclear war would be started during their lifetimes, and 15% thought it was “very likely.” Other surveys by direct interview or questionnaire have been conducted in the United States, the Soviet Union, and elsewhere.[26-28] Although the methodology of some studies has been questioned,[29] their results indicate that many youngsters, particularly from white-collar families, are troubled by the prospect of nuclear war. They have fears about the future, and view their futures less hopefully than previous generations did.

Adults appear to be much more complacent about the threat of nuclear war.[30] For example, the movie *The Day After*, depicting a nuclear war and its aftermath, was shown on network television in the United States in November 1983. The film received extensive publicity and a large audience viewed it. Mental-health professsionals anticipated that the program would generate significant distress in viewers, so they publicized the crisis services that were to be available during and after the broadcast. The Massachusetts Psychological Association had 25 volunteers standing by telephones across the state. Not a single call was received.[20]

Much has been said and written about the apparent apathy of the adult population to the prospect of nuclear self-destruction. Psychic numbing, denial, and other psychological techniques have been proposed as reasons. Despite the horrible possibilities of war, remaining relatively unworried and inactive may not be irrational if people are correct in judging that their activities have no consequence.[31] For example, the citizens of the District of Columbia (“ground zero”) decided by referendum in 1982 that devising a civil defense strategy would be a waste of time.[32]

It is often difficult to distinguish between a lack of concern about nuclear war and an active denial of it.[33] Since children worry about nuclear war and adults generally do not, the process of active denial is suggested. Furthermore, nuclear war

is easy to deny. It is an abstract concept, and we have no experience of it. Many other urgent, immediate things compete for our attention. People seem less motivated by abstract fears than by immediate benefits (life insurance, for example, is sold not on the basis of fear of the future, but rather on the basis of more security today).[30] Denial as a psychological defense may be comforting, but it has its dangers. This trend, thought by some also to exist in the U.S. military,[24] could significantly affect the way one prepares for and functions in a nuclear conflict.[17]

LIMITATIONS ON THE CURRENT DISCUSSION

The circumstances of a tactical nuclear war will dramatically affect predictable psychological outcomes.[34] A strategic exchange of nuclear weapons would be expected to produce more devastation and cause more dramatic emotional changes in survivors than would a single local detonation. But the psychological changes from a tactical nuclear war are not expected to be simple, straight-forward, or minor. One study of predictable troop reactions to a tactical nuclear battle identified specific psychological outcomes to be expected at different times (periods of shock, informal organization, formal organization, and rehabilitation) and distances (zones of destruction, heavy damage, light damage, and periphery) from the nuclear weapon's detonation.[35] The study contains a detailed hypothesis on the spectrum of possible psychological changes in nuclear combatants. This chapter, however, is limited to a general overview of the acute and chronic psychological symptoms that can be expected in soldiers actively involved in a tactical nuclear battle.

No definitive data speak directly to the issue of human psychological responses to radiation exposure or use of nuclear weapons. Experiences of nuclear accident victims have usually been poorly documented regarding mental alterations. Patients who are exposed to ionizing radiation as part of cancer treatment also frequently receive drugs to suppress the side effects and enhance the effectiveness of the radiation. These patients are usually quite sick even before the radiation therapy, so it is difficult to assess the psychological effects of the radiation itself.

A research model for psychological reactions to the nuclear battle has been established by assuming that the reactions are similar to those observed after an intense conventional battle or a natural disaster, such as a flood or earthquake. Although this approach has merit, it also has a number of problems.[36] In particular, the stress of ionizing radiation exposure is missing, with its unique characteristics and implications to those exposed. Persons exposed to radiation on a nuclear battlefield may have little or no initial knowledge of the severity of their radiogenic injuries. This uncertainty, and each individual's interpretation of it, may affect the emotions and ability to perform. These models also ignore the direct radiogenic changes in the CNS, which may also alter the psychological variables.

The data derived from the atomic bombings of Japan are flawed, in part, because the population was predominately civilian. Civilians may or may not react to the use of nuclear weapons in the same way a military force might. Because this was the first use of an atomic bomb, the element of surprise was great. Many of the Japanese citizens were unaware at first that radiation was present. In addition, the radiation doses actually received by persons in Hiroshima and Nagasaki were not well described.

Although the Japanese data are limited, they are too important to ignore. The bombings of Hiroshima and Nagasaki provide the only available data on the combined results of blast, thermal, and radiation insults to a large human population. Some military personnel were present in both cities during the bombings, and provided a few examples of military actions in a nuclear environment.[37] Although data derived from other wars and disasters are not perfect, they can also give clues to the psychological factors in nuclear conflict.

RADIOGENIC CNS CHANGES AND PSYCHOLOGICAL VARIABLES

One aspect of the psychological effects of nuclear weapons that has received little attention is the direct interaction of nervous tissue and radiation. Since the brain is the seat of emotion, ionizing radiation exposure may be capable of directly influencing psychological changes. Especially relevant here are *(a)* data suggesting that the CNS is sensitive to changes induced by ionizing radiation exposure, and *(b)* data suggesting that radiation can change psychological variables in nonhuman animals.

Neurons were once thought to be relatively radioresistant, based on data from studies measuring cell death rather than disruption of cell functioning.[38] More current studies are revising these ideas. Developing cells are particularly sensitive to the lethal effects of ionizing radiation. The adult neurogenesis that takes place in some brain areas in certain animals suggests that these nuclei may be damaged by much lower doses of ionizing radiation (less than 4 Gy) than previously expected.[39] Changes in the amplitude and frequency of EEG recordings occur after 1-4 Gy of X rays,[38] and doses as low as 0.008 Gy can change the spontaneous electrical discharges of hippocampal pacemaker-like neurons.[40] Metabolic alterations of the neurotransmitter dopamine have been reported in the brain after 10 Gy of cobalt-60 radiation.[41] Levels of the putative neuromodulator beta-endorphin also change in irradiated mice and monkeys at doses that do not kill neurons.[42] Neuronal sodium channels may lose their ability to respond properly to stimulation after only 1 Gy of high-energy electrons.[43] Thus, a growing body of evidence suggests that ionizing radiation may alter neural physiology and function at doses substantially below those required to produce morphological changes and neuronal death. It would not be surprising if psychological changes correlate with these changes in brain function.

Acute Psychological Changes

Evidence suggests that emotional variables can be influenced by radiation exposure. It may be possible to study this component of the psychological effects of irradiation by reviewing some of the work done in laboratory animals. The validity of using animals in this kind of work has been detailed elsewhere.[44] This approach has the disadvantage of ignoring (for the moment) some of the psychogenic aspects of a reaction to a nuclear confrontation, but it has the advantage of being able to control the radiation dose and the testing of behavior. The animal data apparently reinforce much of the anecdotal human data from the Japanese experience.

This section addresses the range of psychological phenomena likely to be observed during the first minutes and hours of a nuclear battle, based on both human and experimental animal data. The time course of these acute changes is in question, and the changes may extend for days after the conflict.

Motivation. Motivation may be altered after ionizing radiation exposure. An animal's tendency to perform is governed by a number of factors, including the physical capacity of the animal, rewards or punishments present, and the animal's perception of these reinforcements. If an experimental subject has the capacity to perform in the presence of previously motivating stimuli but does not do so, then it may be inferred that some change in the subject's motivation has occurred. For example, after irradiation, rats will decrease the number of times they press a bar that, when struck, gives them some information about when shock will occur.[45] However, they significantly increase the number of times they press a bar to delay footshock. These data suggest that the animal is fully capable of pressing the bar, but chooses to do so only under certain conditions.

Another study supports this concept. Rats will work in order to receive electrical stimulation of particular brain areas.[46] In one rat, electrodes were implanted into two brain areas (lateral hypothalamus and septum). Before irradiation, the subject pressed the bar at the same rate to activate either site. After irradiation, the animal worked to stimulate only the lateral hypothalamus. Clearly, the animal had the physical capacity to perform the task, but its motivation was altered after irradiation, producing a selective decrease in responding to septal stimulation. These data suggest that motivation may, in some cases, be more radiosensitive than physical capacity.

Some observations have been made about curiosity and investigative behaviors after radiation exposure. Chimpanzees given 3.75-4.0 Gy of gamma radiation made fewer attempts to solve a variety of puzzles. This deficit seems to be independent of changes in capacity, because measures of dexterity and strength were unchanged in these same animals.[47] In another experiment, pairs of monkeys were irradiated with 4 Gy of whole-body X radiation.[48] Twice daily, continuous observations of home-cage behavior were made during a 10-minute period in

accordance with a checklist. In order to control for any debilitation factor, the number of instances of each category of behavior was divided by the total number of times that any identifiable behavior occurred in that same period. In these animals, a reliable deficit in curiosity was measured by the reduced relative frequency of manipulating inanimate objects. The monkeys exhibited relatively more cage-directed movements (toward well-known stimuli) and less attention and orienting to incidental novel noises. They selected food in their central line of sight, rarely choosing food from the periphery. Furthermore, when attempts were made to distract them, they were less likely to orient to the stimuli than were the controls. Because this procedure attempted to factor out general malaise, the results suggested reduced levels of curiosity and attention in the animals.[49,50] These observations agree with others in which irradiated monkeys showed increased performance of tasks that placed a premium on attention to a known site of food reward. Conversely, the monkeys showed reduced performance of tasks that required attention to stimuli in the periphery of vision.[48]

The data from Hiroshima and Nagasaki suggest that a similar change in motivation may occur in humans exposed to the trauma of a nuclear detonation. The defensive mechanism of "psychic numbing" or "psychic closing off" was observed in the atomic bomb victims.[19] One writer described this scene:

> Those who were able walked silently toward the suburbs in the distant hills, their spirits broken, their initiative gone. When asked whence they came, they pointed toward the city and said "that way;" and when asked where they were going, pointed away from the city and said, "this way." They were so broken and confused that they moved and behaved like automatons.
>
> Their reactions astonished outsiders who reported with amazement the spectacle of long files of people holding stolidly to a narrow, rough path when close by was a smooth, easy road going in the same direction. The outsiders could not grasp the fact that they were witnessing the exodus of a people who walked in the realm of dreams.[51]

These data are consistent with others from Hiroshima reporting "fatigue," "mental weakness," "spiritual desolation," or "closing off."[37] Certainly, in the case of these atomic-bomb survivors, this change in motivation cannot be solely attributed to a dose of radiation. These people had just witnessed the devastation of their homes and, in many cases, the deaths of family members. Thus, it is very likely that these behavioral and psychological changes may have a psychogenic component, which may compound the radiation-induced alterations described above in laboratory animals.

Despite the emotional deadening and "mental weakness" reported by almost everyone influenced by the bombing of Hiroshima, it is remarkable how much

physical activity was exhibited by some of the survivors. Some of this activity seemed ill directed:

> There was no organized activity. The people seemed stunned by the catastrophe and rushed about as jungle animals suddenly released from a cage. Some few apparently attempted to help others from the wreckage, particularly members of their family . . . However, many injured were left trapped beneath collapsed buildings as people fled by them in the streets.[52]

This account of frantic activity raises the issue of panic. Was there mass panic after the dropping of the atomic bomb? Probably not. Although several isolated instances of aimless and hysterical activity have been reported, these did not seem to be typical behaviors. Disaster victims are extremely concerned about how the disaster will affect the things and persons they value. They want to know what has happened to those they hold dear, and they want to help them if necessary. This concern often leads to a great deal of activity, which may appear to an observer as irrational and disorganized. Thus, the very rational and deliberate flight of people from an area of danger (a highly adaptive behavior) is often mistakenly described as panic.[35] Reports from the U.S. Army (which interviewed the survivors of the bombing)[21] did not support the claim that a sizable portion of the population behaved in an ineffective, nonsocial, or nonrational way.[53] The report also clearly indicated that many people felt terrified or fearful, even though they did not exhibit panic reactions. In only a few cases can one surmise from interviews that individuals might have exhibited uncontrolled emotional behavior. Instead, compliant, subdued behaviors were more prominent, perhaps mediated in part by some radiogenic CNS effects or other injuries:

> Many, although injured themselves, supported relatives who were worse off. Almost all had their heads bowed, looked straight ahead, were silent, and showed no expression whatsoever.[52]

It seems that a depressed motivational state, rather than panic, was a typical reaction to the disaster.

Obviously, either a chaotic or an apathetic response to a bombing would not be adaptive in a military environment. Some evidence exists that inhabitants of Hiroshima who had a specific job to perform or a goal to meet tried valiantly to do so after the bombing. A group of wounded soldiers was observed gamely attempting to struggle out of the disaster area in military formation:

> At Misasa Bridge, they encountered a long line of soldiers making a bizarre forced march away from the Chugoku Regional Army Headquarters in the center of the town. All were grotesquely burned, and they supported themselves with staves or leaned on one another.[37]

One account of a young Japanese soldier is particularly relevant here:

> We were under military order to return to our unit immediately in case of any attack or emergency, so I returned almost without thinking . . . At first I couldn't get through . . . so in the evening I started out again. This time I didn't try to help anyone but just walked through them. I was worried about the Army camp because according to what people told me, it had simply gone up in flames and disappeared. I was also a bit ashamed about having taken such a long time to return. But when I finally got back to camp, just about everyone was dead—so there was no one to scold me . . . Next thing I did was to look for the ashes of the military code book— since we had a military order to look for this book even if it were burned, as it was a secret code which had to be protected. Finally I located the ashes of the book, and wrapped them in a furoshiki and carried this around with me. I wanted to take it to the military headquarters as soon as possible, but when I finally did take it there in the morning, the officer scolded me for doing such a stupid thing . . . I was fresh from the Military Academy and my head was full of such regulations.[54]

Some of these phenomena may be explained by *attentional focusing*, a behavior similar to that which was exhibited by irradiated laboratory animals. These people tended to focus on a particular aspect of their environment and to pursue it, sometimes to an illogical or inappropriate end. The soldier above pursued his assigned task, ignoring the fact that the nuclear detonation had totally changed his world (a behavior that would not necessarily be discouraged by military commanders). Thus, although a generalized decrease in motivation may have occurred in much of the Hiroshima population, some behaviors directed toward a well-defined goal apparently persisted after the catastrophe.

Fear and Terror. The main reaction of the Japanese populace in the atomic-bomb target areas was "unqualified terror," fed by the horror of the destruction and suffering either witnessed or experienced by the survivors.[21] Sixty-three percent of all respondents to the U.S. Strategic Bombing Survey reported either generalized terror or fear for one's own life. Some experiences cannot be described by cold figures:

> People were running toward our place with terrible burns. That night they slept on the road everywhere. Some collapsed during the day due to the effects of burns. People would stop by and ask for water, which was the most urgent need of these people. They were so upset that they couldn't think of food. It was a horrible sight—crying and screaming. I can't describe the burns that were on these people, and the odor of burning flesh was in the air, and it was so awful you have to see it before you can actually describe it or even

> talk about it. It's hard to comprehend. Some father with his entire family dead would be yelling to die, so that he would not have to live alone.[21]

Social Relations. It is of psychological and social importance that, in the extreme trauma after the atomic explosions in Japan, most people behaved in a manner compatible with established social norms.

> To Father Kleinsorge, an Occidental, the silence in the grove by a river, where hundreds of gruesomely wounded suffered together, was one of the most dreadful and awesome events of his whole experience: The hurt ones were quiet; no one wept, much less screamed in pain; no one complained; none of the many who died did so noisily; not even the children cried; very few people even spoke. And when Father Kleinsorge gave water to some whose faces had been almost blotted out by flash burns, they took their share and then raised themselves a little and bowed to him in thanks.[37]

With the disruption of individual motivation, people seemed most likely to pursue the goals established by others. Attention to leaders did not seem to be jeopardized after the detonation. For example, a victim of Hiroshima recounted:

> All the people were going in that direction and so I suppose I was taken into this movement and went with them . . . I couldn't make any clear decision in a specific way . . . so I followed the other people . . . I lost myself and was carried away.[54]

Various cultures may differ on the issue of conformity. But if we can generalize from these data, we can expect the social structure to be maintained after a nuclear conflict.

Learning and Memory. The results of animal studies are consistent with the hypothesis that functions of learning and memory may be altered by some doses of radiation. For example, rabbits learned to associate a tone and a light with apnea produced by inhaling ammonia vapor.[39] Once this classically conditioned response was established, the tone and light alone produced apnea. However, after irradiation (15 Gy), the conditioned response was absent or considerably reduced in duration. In contrast, the apnea produced by the ammonia itself was enhanced after radiation exposure (confirming that the animal was still capable of this response). Retrograde amnesia has also been reported in rats exposed to rapid, low doses (0.1 Gy) of electrons.[55]

Interviews with people exposed to radiation at Hiroshima indicated few cases of acute retrograde amnesia in the population.[52] However, 5 years after the detonation, deficits in memory and intellectual capacity were noted in persons who

had experienced radiation sickness.[56] Acute radiogenic impairments of memory in the human have also been reported in the Soviet literature.[57]

Chronic Psychological Reactions

The initial reactions to a nuclear weapon detonation may be quite different from reactions that occur after weeks, months, or years. Psychogenic changes in emotionality, personality, and somatic effects usually take a period of time to be expressed fully. Studies of psychological symptoms in various cultures after the death of a loved one reveal that reactions to grief are seldom completed in less than 1 or 2 years. The more severe or complicated the loss or injury in a disaster, the more extended the reaction time may be.[58] These data suggest that significant chronic psychological dysfunctions may occur in nuclear combatants.

Psychoses. Serious psychological derangements involving distorted perceptions of reality and thought were rare after the atomic-bomb detonations, just as they were after the large-scale conventional bombings of World War II.[59] The incidence of psychosis (mainly schizophrenia) in military populations is similar in peace and war.[10] This is confirmed by evidence that a variety of traumatic situations are not associated with an increased rate of psychosis. For example, massive aerial bombardment of population centers in England, Germany, and Japan during World War II did not produce an increased number of psychoses, as indicated by mental-hospital admission records. Similarly, psychoses do not usually result from spontaneous civil disasters (such as hurricane, tornado, or fire).[60] It appears that psychoses are not the result of external danger. When units new to combat are exposed to severe battle stress, they frequently exhibit severe behavioral disorganization and disorientation, hallucinations, and even mute, catatonia-like states. These conditions are transient and usually subside in 1-3 days to become typical cases of neurosis.

Neuroses. Neurotic reactions to the traumas of nuclear combat are to be expected. Among 7,297 patients exposed to ionizing radiation during the atomic bombings of Japan, 533 patients had neurosis-like symptoms.[56] The patients were divided into two groups: those with symptoms of atomic-bomb radiation illness and those without. Neurosis-like symptoms were twice as common in the former group as in the latter. The Japanese researchers pointed out that some of these cases were recognizable as "pure neuroses" caused by psychogenic factors (other than the bombings), but that others could be caused by functional disorders of brain or body due to radiation. Not surprisingly, the more severe the symptoms of atomic-bomb radiation illness, the stronger the neuropsychiatric aftereffects. The common symptoms included weariness, lack of spirit, a tendency toward introversion, and poor memory.

Post-Traumatic Stress Disorder. Seeing large numbers of burned, cut, and maimed bodies was a major source of emotional trauma after the bombing of Hiroshima. Many survivors located a short distance from the center of the

explosion received two emotional shocks: the first from the physical impact of the explosion, and the second after they ran out into the streets and saw so many casualties. Among those at the periphery who escaped the full physical violence of the explosion, the first emotional impact seems to have occurred when they saw the streams of injured victims pouring out of the destroyed areas. Apparently, it was not only the large number of casualties but also the specific character of the injuries (particularly the grossly altered physical appearance of persons with severe burns) that produced emotional disturbances in the people who saw them.[54] For example,

> I walked past Hiroshima station . . . and saw people with their bowels and brains coming out . . . I saw an old lady badly burned and carrying a suckling infant in her arms . . . I saw many children . . . with dead mothers . . . I just cannot put into words the horror I felt.[54]

Post-traumatic stress disorders (PTSD) are seen after a variety of natural disasters[61] and should be expected after the shock of a nuclear conflict.[62] The full PTSD syndrome is a cluster of symptoms occurring after exposure to unpredictable life-threatening environmental trauma.[63] Sufferers of chronic PTSD continue to live in the emotional environment of the traumatic event, with prolonged vigilance for and sensitivity to external threat. The five principal features of PTSD are *(a)* persistence of startle responses and irritability, *(b)* proclivity to react explosively, *(c)* fixation on the trauma, *(d)* constriction of the general level of personality functioning, and *(e)* an atypical dream life.

A numbing of responsiveness, reduced involvement with the external world, and constricted affect are part of the diagnostic criteria established for PTSD.[64] Long-term depressive reactions with these characteristics have been reported to occur after catastrophic natural disasters, such as floods.[65] Depression is one of the prominent symptoms observed in soldiers during the extreme stresses of combat.[2] Although acute depression (evidenced by weakness and lethargy) characterized much of the Hiroshima population for a few days after the bombing, it is difficult to say if significant numbers of people experienced chronic depression. Although individual questionnaire responses from Hiroshima residents seemed to describe a depressive reaction in many cases, statistical analyses revealed no greater incidence of depression there than in other Japanese cities.[52] This may be misleading, however, because postwar apathy seemed to characterize most of the population of Japan. Chronic depressive reactions have been known to follow a variety of traumas, so they are not exclusive characteristics of nuclear disasters.

Anxiety and Phobias. In view of the horrors of the nuclear detonations in Japan, it is not surprising that severe anxiety persisted for many days and sometimes for weeks and months, according to various sources.[21] One of the most frequent types of sustained emotional disturbance appears to have been a phobia-like fear of exposure to another traumatic disaster. This reaction consisted of strong feelings

of anxiety and exaggerated efforts to ward off new threats. A physician in Hiroshima wrote:

> Whenever a plane was seen after that, people would rush into their shelters. They went in and out so much that they did not have time to eat. They were so nervous they could not work.[52]

Another author described the following: "It began to rain . . . The drops grew abnormally large, and someone [in the evacuation area] shouted, “The Americans are dropping gasoline. They're going to set fire to us!’”[37]

Further indications of sustained apprehension in Hiroshima came from the anxiety-laden rumors reported to circulate during the postdisaster period.[52] For example, one woman reported:

> I heard that people who had not been wounded and seemed to be all right would begin feeling out of sorts and all of a sudden drop dead. It made me panicky. Here I was bustling around now, but I might go off myself.[52]

Most of the survivors had never heard of radiation sickness and were unprepared for its manifestation. During the weeks following the atomic explosions, many survivors began to exhibit signs of organic pathology: loss of hair, high fever, excessive fatigue, hemorrhagic spots under the skin, and other severe symptoms of what we now recognize as ARS. Witnessing the agonizing deaths of children and relatives probably touched off or reinforced rumors and sustained the fear reactions created by the disaster.[52]

Rumors may play a significant part in any future nuclear combat. Communication on the nuclear battlefield will be disturbed by electronic warfare tactics and by the spreading of deliberate misinformation by the enemy. Negative rumors can be expected in any population if radiation is a perceived threat.[66]

Survivor Guilt. Although the adherence to social customs seemed to be strong after the atomic bombings, not everyone acted in a completely altruistic fashion. It was impossible to do so, given the sheer number of casualties. Some people fought fires and fed the hungry, but most people (especially those who did not work in the helping or service professions) restricted their assistance, when they could give it, to people they knew: “Under many houses, people screamed for help, but no one helped; in general, survivors . . . assisted only their relatives or immediate neighbors, for they could not comprehend or tolerate a wider circle of misery.”[59] As one survivor summarized, “The idea of 'love thy neighbor as thyself' that I always believed in, had disappeared some place. I guess it was too much for any of us.”[67] Persistent survivor guilt may be an inevitable consequence of atomic bombing. People in the heart of the city were able to survive only by running away from the fires without stopping to rescue others. People who were in a

position to give aid could not simultaneously perform all the duties and obligations of rescuing the wounded, rushing to their own families, assisting neighbors, carrying out their civil defense assignments, saving valuable materials at the offices or factories where they worked, preserving treasured household articles, and so on. Although independent observations indicate that some survivors experienced temporary guilt reactions following the atomic bombings, no satisfactory evidence supports the claim that such reactions persisted in large numbers of survivors or for very long periods of time.[52]

Psychosomatic Symptoms. Some patients may have had a psychosomatic "atomic bomb neurosis," in which the survivor's identification with the dead and maimed initiates a vicious psychosomatic circle.[36] Such a survivor is likely to associate the mildest everyday injury or sickness with possible radiation effects, and anything that could relate to radiation effects becomes associated with death:

> Frankly speaking, even now I have fear . . . Even today people die in the hospitals from A-bomb disease, and [when I hear about this] I worry that I too might sooner or later have the same thing happen to me . . . I have a special feeling that I am different from ordinary people . . . that I have a mark of wounds—as if I were a cripple . . . It is not a matter of lacking something externally, but rather something like a handicap—something mental that does not show—the feeling that I am mentally different from ordinary people . . . so when I hear about people who die from atomic bomb disease or who have operations because of this illness, then I feel that I am the same kind of person as they . . .[54]

Thus, combatants involved in a nuclear battle may "share" physical symptoms of radiation sickness. This adoption of symptoms may be due, in part, to not understanding their disorders and also to anxiety about the lethal effects of radiation exposure. Physicians may be caught in a conflict between the humanitarian provision of medical care and the danger of encouraging the development in survivors of hypochondria, general weakness, and dependency.

SUMMARY OF PSYCHOLOGICAL EFFECTS

Although the atomic bomb experience in Japan is the best model available, it is difficult to determine how much information this model and correlated animal data can provide on the psychological changes in a military nuclear confrontation. All psychological effects (like all physiological effects) are dependent on the dose of radiation received; the distance from ground zero (and correlated blast and thermal effects); and the indefinable personal, psychological, and social background of the potential nuclear victim. However, if we can assume a certain degree of congruity between the psychological response of the Japanese and the expected response of military personnel, the following summary may apply.

With ionizing radiation exposure will come alteration of CNS physiology, which in turn may bring about acute behavioral and psychological changes, such as a generalized reduction of motivation. There may also be symptoms of lethargy and fatigue, which will inhibit the likelihood of generalized panic. Persons will still be able to take direction, but the capacities to learn and remember may be changed. The horrible wounding and destruction produced by a nuclear weapon could be expected to have immediate psychological effects on the military personnel who observe them. If they react like the citizens of Hiroshima, they will be fearful and anxious, perhaps even more so than during a conventional conflict. These symptoms may be heightened by rumor and by any misinformation about the threat. Group cohesion will contribute to the likelihood of altruistic behaviors, but self-preservation may be a more compelling need for many. Social order (military protocol) will probably remain intact in many cases. Longer-term psychological reactions may include phobias, PTSD, depression, and various psychosomatic symptoms. Guilt concerning questions of personal survival and inadequacies in performance could contribute to the development of neurotic symptoms, as will the severity of physical wounding. Psychotic reactions are probably less likely to occur.

PREDICTION OF NEUROPSYCHIATRIC CASUALTIES

It is important to know how severely these psychological changes will affect the performance of military units or the outcome of a nuclear battle.[8,2,68] The distribution of the psychological effects of a nuclear disaster may be consistent with a normal curve.[62] Here, as in other disasters, most survivors (about 75%) would manifest a few of the symptoms described above. About half of the remaining survivors would be almost totally unaffected, and the others would show many or a high degree of acute and chronic psychological changes. If tactical nuclear weapons are used in combination with the extensive conventional arsenals that are available, then the predicted neuropsychiatric casualties in a nuclear battle would exceed those expected in a conventional conflict. Since the psychological casualties of high-intensity conventional warfare may be 18%-48% of the total casualties under certain circumstances, it can be expected that psychological factors will play a substantial role in determining the outcome of a nuclear battle.

CARE OF PSYCHOLOGICAL CASUALTIES

Some of those with minor emotional symptoms will never be seen clinically. However, the literature suggests that those who do find their way to psychological treatment should be handled in conventional ways.[2] These techniques involve the principles of *proximity, recency,* and *expectancy*. Individuals respond better if they receive therapy as soon as possible and as near as possible to the scene of the battle. Medical personnel should calmly accept the person's problems and regard them as a temporary incapacity, with recovery expected after a brief rest. The

condition of persons with situationally induced, acute psychological disorders will worsen or improve, depending on what is expected from them by the providers.[3] In World War I, military psychiatrists came to recognize that the “shell shock” syndrome was fostered by prolonged hospitalization and then evacuation to the zone of the interior.[8] However, some British officers noticed that if the shell-shocked soldiers were treated quickly and near the front line, 70%-80% soon returned to full duty.[69] When soldiers are evacuated from the combat area, a vicious circle may be set in motion.[70] Removal from the front and admission to a hospital confirm their belief in the seriousness of their condition. Then they discover (unconsciously or consciously) that their illness is an asset that keeps them out of combat. Under these conditions, symptoms may become fixed and the soldiers may become incapacitated for further combat duty. The practice of forward therapy was developed from these observations. If combat soldiers who become neuropsychiatric casualties are not long separated from their groups and are quickly treated in the vicinity of the fighting, they can frequently rejoin their units in a few hours or days. The treatment includes some simple therapy with an interview, rest, perhaps sedation, and individual or group psychotherapy, followed by a return to duty accompanied by friends. This is combined with assurances from the medical personnel that their symptoms are natural ones that may break out in almost any soldier under enemy fire.[71] Although some of these techniques have been recently questioned,[72] they were proven to be useful as recently as the Israeli war experiences of 1973 and 1982, in which a few aggressive teams returned 95% of battle-shock cases to duty with their units.[4]

This conventional approach to treatment is effective, but a nuclear conflict will present special problems to medical personnel. One problem is the uncertainty of personal injury. Most people now realize that radiation exposure can be lethal even though initial effects may be minimal. This uncertainty about one's health after irradiation will increase the medical treatment load. It has been shown in previous studies of disasters that threats or dangers that cannot be reliably perceived by the senses can cause considerable psychological disturbance. For example, a mass poisoning of bootleg whiskey in Georgia resulted in a large number of people seeking emergency medical treatment. When tested, about 40% were unaffected by lethal alcohol; some confessed that they did not know if they were affected, but they wanted to be checked.[73] Under a current military plan, each soldier will be provided a dosimeter the size of a wristwatch before a nuclear battle, but it will be possible to read the dose only by using a heavy, bulky device at the unit's headquarters.[24] After a nuclear attack, many soldiers will wish to be reassured that they have not been exposed to appreciable levels of radiation.[73] The situation may be similar to one in World War I in which mustard and phosgene bombardments (both of which have delayed effects) were first used. For every true case of gas exposure evacuated to the field hospitals, two soldiers were evacuated who only believed they had been gassed.[24] Without information, combatants are more likely to overestimate the danger and to succumb to rumor and hysteria. This could add to the chaos that may already exist at the treatment centers.

Knowing that medical care is available has always provided comfort to combatants, but the Japanese experience[70] as well as current estimates[23,74] suggest that medical facilities will be stressed, if not overwhelmed, after a nuclear conflict. For example, burn cases place a great strain on medical personnel. Using evidence from the English experiences of World War I, the British Army Operational Research Group estimated an average time of 52 minutes for three persons to simply dress a burned hand.[75] Extrapolations from their data suggest that the requirement for treating 1,000 serious burn cases would be 5,000 health professionals and 235 tons of supplies. Based on a case in which a 38-year-old man was accidentally exposed to 2 Gy of cobalt-60 radiation, others have conservatively estimated that the cost of treating such a person would be $22,000 (in 1982 dollars). It is doubtful that such extensive care could be guaranteed to large numbers of battlefield casualties. If the medical load becomes too extensive and reasonable care cannot be given to casualties, morale will suffer. The detrimental effect of inadequate medical care on morale was noted in the Hiroshima experience, in which many medical facilities were destroyed. The care was so limited that it may have been a factor in some acute depressive reactions and feelings of helplessness following the bombing.[37,76]

In addition, the concept of removing combatants from the field for psychological treatment and then returning them better prepared to deal with the stresses of combat may be less useful in a nuclear conflict. Removal from the conventional battle allows psychological and physical healing. However, in some cases, the progressive physical radiation effects may continually erode the individual's ability to perform a task that is necessary for the success of a military mission. The efficacy of removing psychologically impaired irradiated soldiers from the battlefield with any expectation of their return is questionable.

An ethical dilemma may present itself with soldiers who are believed to have received intermediate doses of radiation that may kill them, but who can almost certainly be saved by treatment in a secure hospital setting.[24] A researcher writes,

> Should he be evacuated, and [the unit] lose a potentially effective soldier during the latent phase? Or should he be returned to duty, knowing that he has a greatly increased risk of death from disease or injury, even if not killed by enemy action, due to impaired blood clotting, wound healing, and resistance to infection?[24]

These are difficult issues. They deserve our attention now, before a nuclear weapon is used again.

PREVENTION OF PSYCHOLOGICAL CASUALTIES

Steps are available to reduce psychological problems after a nuclear confrontation. Proper training and preparedness apparently provide some degree of protec-

tion. The benefits of training are confirmed by the remarkable experiences of nine persons who survived the Hiroshima bombing and then fled to Nagasaki in time for the second atomic bomb.[15] They remembered very well what they had done that allowed them to live, and they quickly instructed others in Nagasaki:

> Yamaguchi's lecture on A-bomb precautions, he pointed out later, was not lost upon his colleagues. With the young designer's words still fresh in their minds [at the time of the second bombing] they leaped for the cover of desks and tables. "As a result," said Yamaguchi, "my section staff suffered the least in that building. In other sections there was a heavy toll of serious injuries from flying glass."[15]

In the most beneficial type of training, emphasis should be on *(a)* realism, in order to reduce the psychological shock of a nuclear confrontation, *(b)* accurate information about the threat, and *(c)* information that not only can be readily comprehended and assimilated by the average person but also can be directed toward self-preservation.[2] Recent recommendations have called for the use of a nuclear simulator in order to desensitize soldiers to the unique destructiveness of a nuclear battle.[24] The following training may help to prevent psychological casualties in a nuclear war:

> First, every soldier should be trained in methods of individual protection against atomic attack, for both the actual protection and the self-confidence which such knowledge will give . . .
>
> Second, individual soldiers should be given training designed to enable them to reorient themselves after atomic attack. This should include training in methods of determining whether the attack involved an air or ground burst, in methods of estimating their own location with reference to the center of the disaster area, and in the use of instruments for the measurement of radioactivity.
>
> Third, individuals should be taught that they are not defenseless against atomic attack, but that they should not expect to survive such an attack without suffering severe shock effects and seeing many of their own forces killed or wounded.
>
> Fourth, individuals of all ranks should be impressed with the importance of offering all the resistance of which they are capable to ground assault following an atomic attack, no matter how hopeless and ineffective it may seem.
>
> Fifth, indoctrination should teach soldiers that the role of troops subjected to atomic bombing will very likely be that of delaying the enemy ground assault at all costs until relatively unharmed

> reserves can establish an effective defense or launch a coordinated counterattack.
>
> Sixth, all personnel should be impressed with the importance of giving absolute priority to traffic moving towards the front following an atomic attack, no matter what their own reasons for moving toward the rear may be.[35]

The forces of social cohesion will also influence the psychological and performance variables after a nuclear weapon detonation. The single most important factor that sustains soldiers in combat is the powerful psychological support of their fellows—the squad, platoon, company, and so on.[2] Isolation increases stress and also reduces the soldier's capacity to resist the effects of that stress. Various historical accounts have suggested that an isolated soldier is more likely to surrender than another member of the group who is in the same tactically hopeless situation but is still bound by the continuous ties of fighting, eating, and sleeping next to fellow soldiers.[2] Also, a significant relationship exists between a group's cohesion, its confidence in combat skills, and measures of its actual performance. The Israelis reported almost no psychiatric casualties in their elite (and cohesive) airborne forces, regardless of the intensity of combat in the 1973 Yom Kippur War.[1] The ability of the primary group to resist disintegration will greatly affect the capacity of its members to withstand the stress of a nuclear confrontation. However, we should recognize that disruption of the primary group by loss of personnel and leadership, breaks in communication, and deterioration of supply and medical care are more likely to occur in nuclear combat than in conventional confrontations.[2]

Much of the current training promotes hopelessness in our military forces and drives them further into avoidance and denial.[24] More work needs to be done to meet the training needs outlined above and to prepare for the expected psychological reactions to the use of nuclear weapons.

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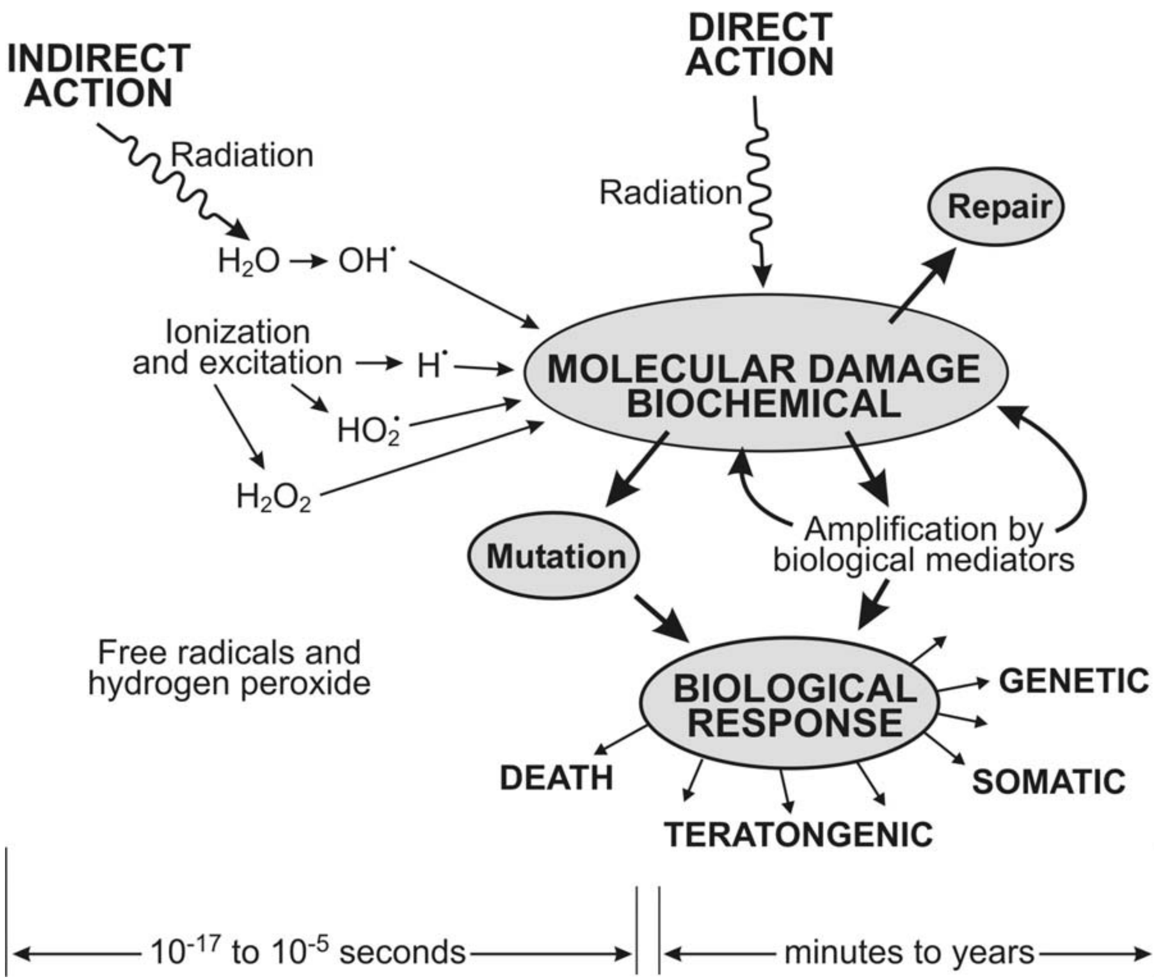

Figure 9-1. Physical and biological responses to ionizing radiation. Ionizing radiation causes damage either directly by damaging the molecular target or indirectly by generating free radicals, which attack the molecular target. Physical steps leading to energy deposition and free radical formation occur within femtoseconds to microseconds, while the manifestation of actual biological damage may require seconds to years.

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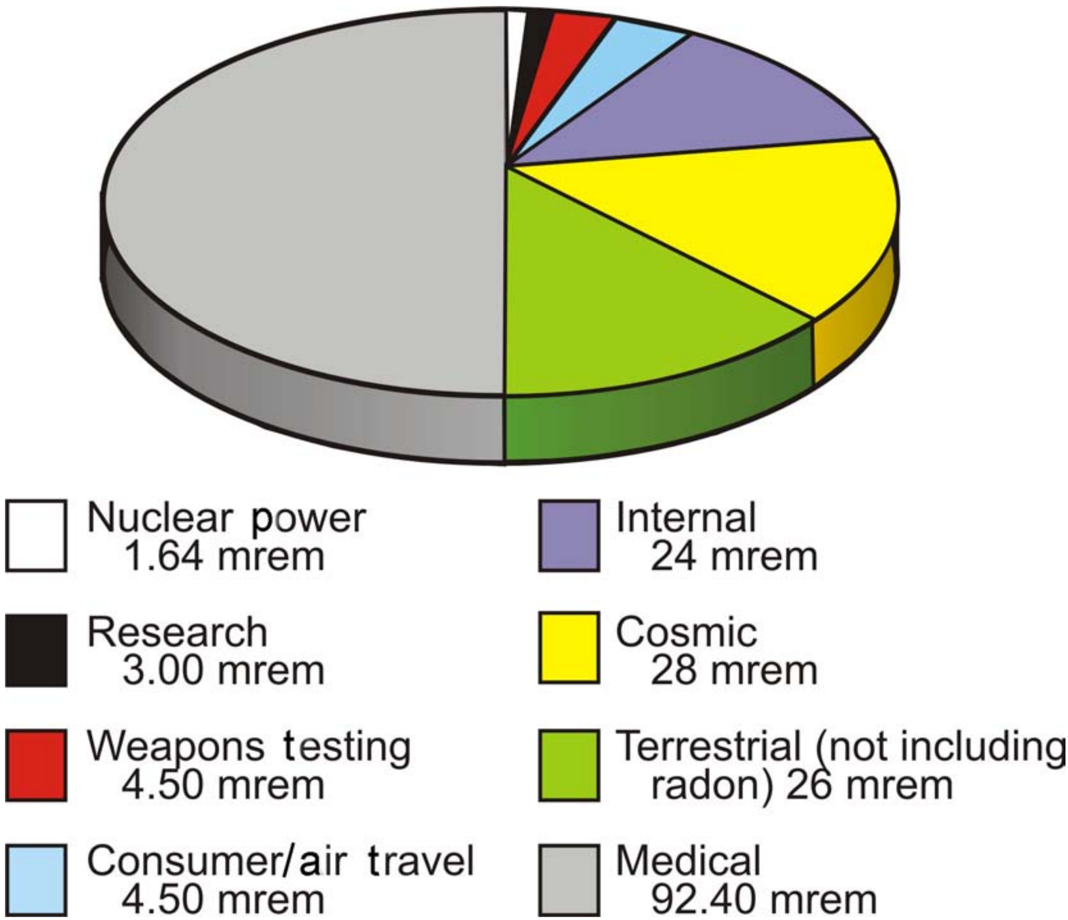

Figure 9-2. Major contributors to average background radiation in the United States.

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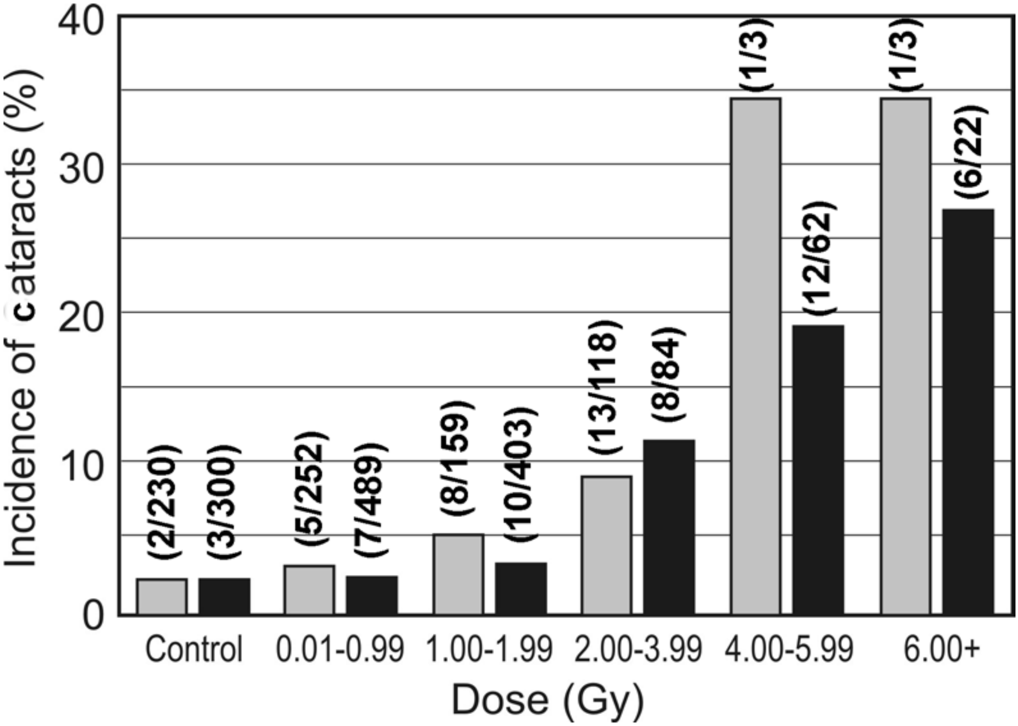

Figure 9-3. Incidence of severe cataracts in atomic-bomb survivors, according to radiation dose received. Cataracts were detected by examinations in 1963-1964 for populations of Nagasaki and Hiroshima. Numbers in parentheses are the actual numbers of cataracts observed per number of persons examined who received that dose of radiation. Radiation doses are based on Oak Ridge National Laboratory (ORNL) calculations, which contain a lower neutron dose estimation in the Hiroshima population than originally estimated. Based on the 1965 tentative dose relationship (T65D) estimate, the average total dose for the 600+ Hiroshima group is 7.783 Gy, including 2.343 Gy of neutrons. Using ORNL dosimetry, the average dose for this group is 8.514 Gy, with 0.74 Gy of neutrons. Dosimetry was recently revised based on new information on explosion characteristics. Risks will be revised by scientific advisory boards when these new estimates (DR86) become available. Source: References 107 and 108.

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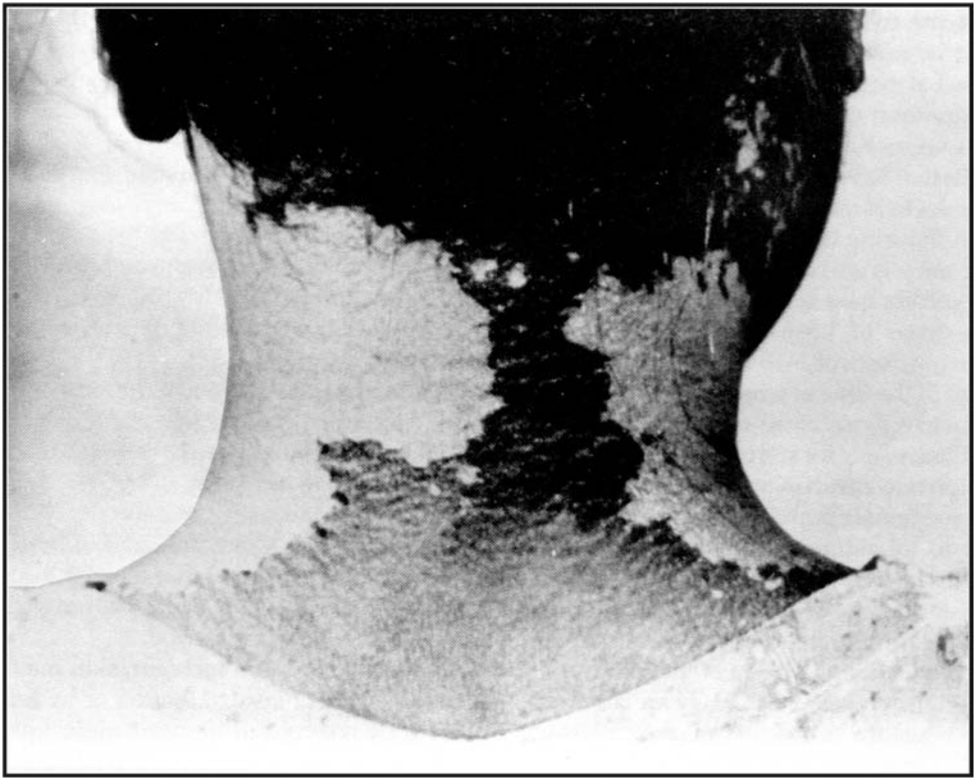

Figure 9-4. Beta burn on neck of Marshall Island woman 1 month after exposure to fallout radiation from a nuclear weapon. Note discoloration of skin on left and right sides.

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Figure 9-5. Clinical course of radiation damage to the skin of a radiotherapy patient: (A) erythema, (B) erosion, (C) ulcer, (D) scar. Source: Reference 45.

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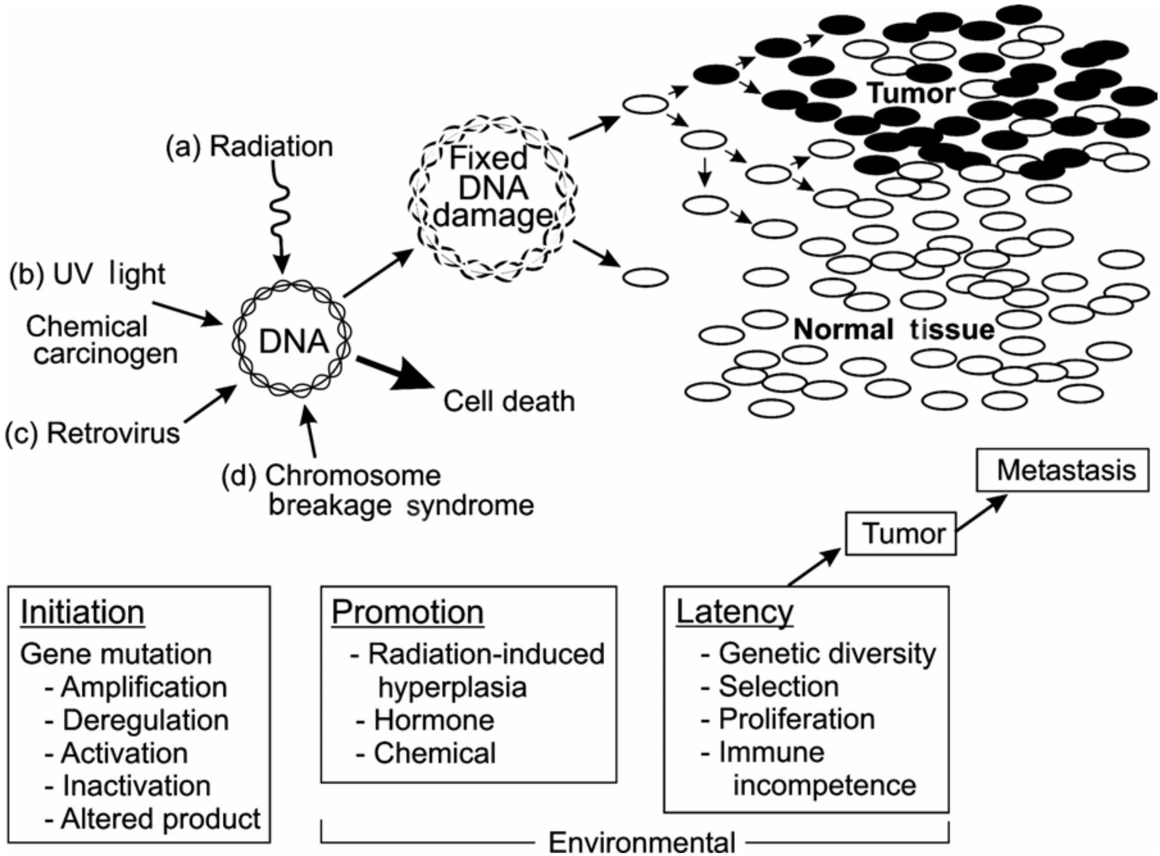

Figure 9-6. Sequential steps in the development of cancer. Cancer originates from a single cell (clone) through a multistep process. Initiation by one of four methods (a-d) leads to repair of damage, or cell death, or fixation of DNA damage, which may predispose the cell to transition into a neoplastic state. Chromosome-breakage syndromes (also called genetic syndromes, such as xeroderma pigmentosum and ataxia telangiectasia) are associated with deficiencies in DNA repair and genetic instability. Environmental or host factors may play roles in cancer promotion and latency. End products of these steps are the tumor and its potential metastases.

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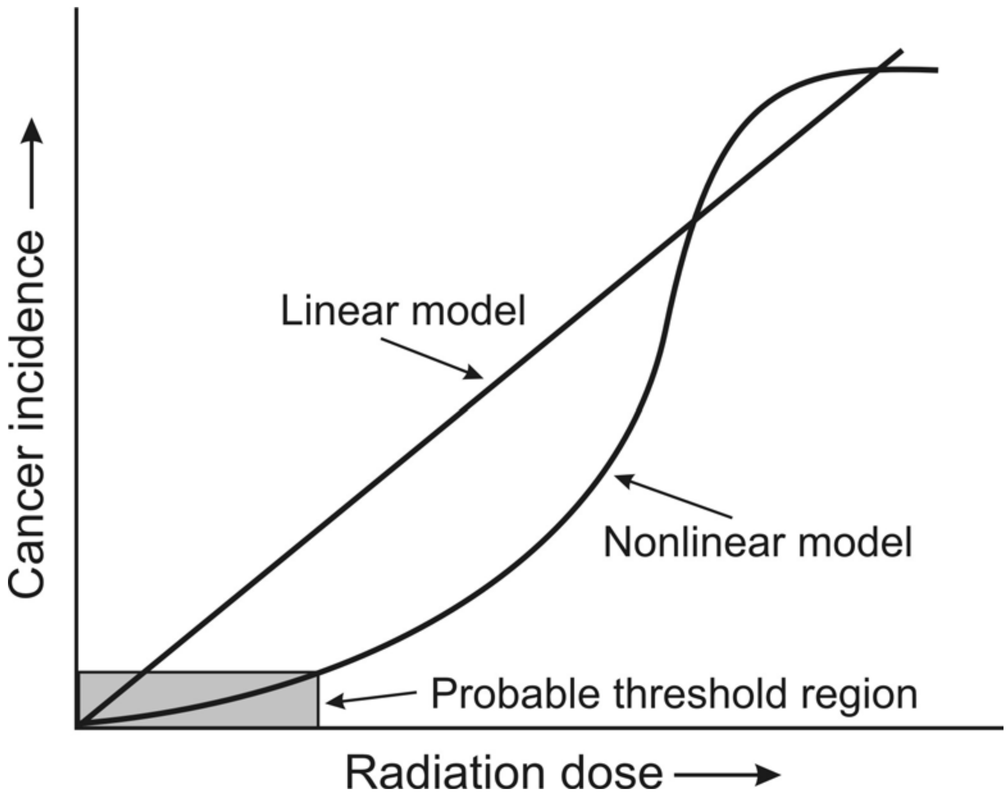

Figure 9-7. Mathematical models for radiation dose and incidence of cancer. Four models estimate the effects of low-level radiation on incidence of cancer: linear model with threshold, linear model without threshold, nonlinear model with threshold, and nonlinear model without threshold. A “quasi” or probable threshold may exist in the nonlinear model (shaded area), where an increase in incidence within that region is so low that a threshold essentially exists.

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Figure 9-8. Incidence of leukemia in Nagasaki atomic-bomb survivors through 1972. Bone-marrow doses have been adjusted for differences in age at time of exposure, and 50% confidence intervals are provided. Relative fits of four different mathematical models to data are shown: pure quadratic with cell killing (– •– •–), pure quadratic (▬ ▬ ▬ ▬), linear-quadratic (•••••••••), and linear (——). Insert is enlargement of the dose rate (< 0.2 Gy). Source: Redrawn from reference 102.

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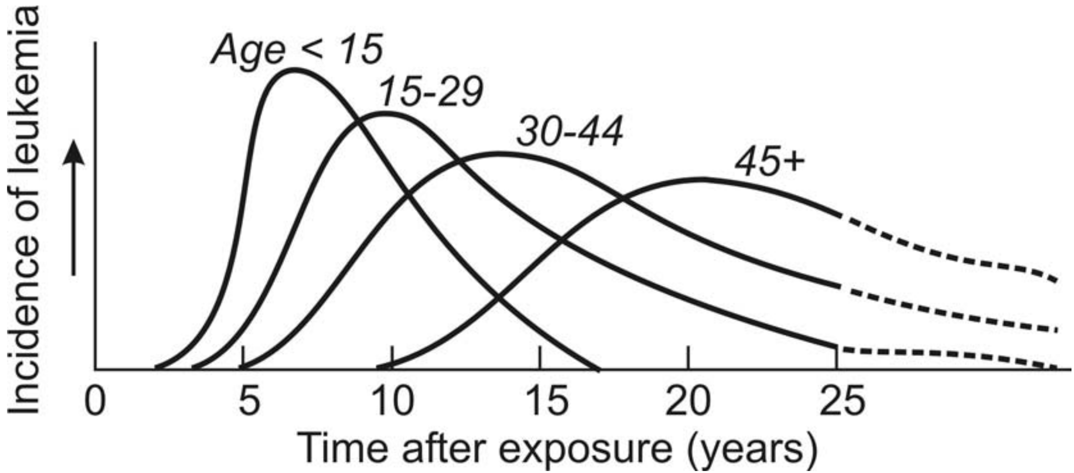

Figure 9-9. Effect of age at time of radiation exposure on incidence of leukemia in atomic-bomb survivors. Radiation-induced risks are shown for all forms of leukemia (combined) relative to age at time of atomic-bomb explosions, based on 1977 data. Chronic lymphocytic leukemia is not included because increased incidence has not been observed in any exposed human population. Source: Reference 118.

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Figure 9-10. Incidence of thyroid cancer in atomic-bomb survivors. (A) Incidence of thyroid cancer as a function of dose and gender (male □, female ■). Data were obtained in 1964 study of thyroid neoplasm. (B) Incidence of benign (□) and malignant (■) thyroid neoplasm in persons who had received therapeutic radiation for tinea capitis. Source: (A) redrawn from reference 130; (B) redrawn from reference 128.

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Figure 9-11. Incidence of breast cancer as a function of fractionated versus acute radiation exposure. The incidence of disease appears to be similar (within statistical limits) whether women received a single acute exposure, as in atomic-bomb survivors (■), or a fractionated series of smaller doses, as in mastitis patients (•) and fluoroscopy patients (▲).Source: Redrawn from reference 142.

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Figure 9-12. Mortality rate from lung cancer related to cigarette smoking in atomic-bomb survivors. Mortality in 1965-1978 is for persons exposed to 0-0.09 Gy (□) and >1 Gy (■).

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Figure 9-13. General structures of the four bases of DNA. Three hydrogen bonds occur between cytosine (C) and guanine (G), and two between adenine (A) and thymine (T). Several types of radiation damage to DNA are shown. Source: Redrawn from reference 247.

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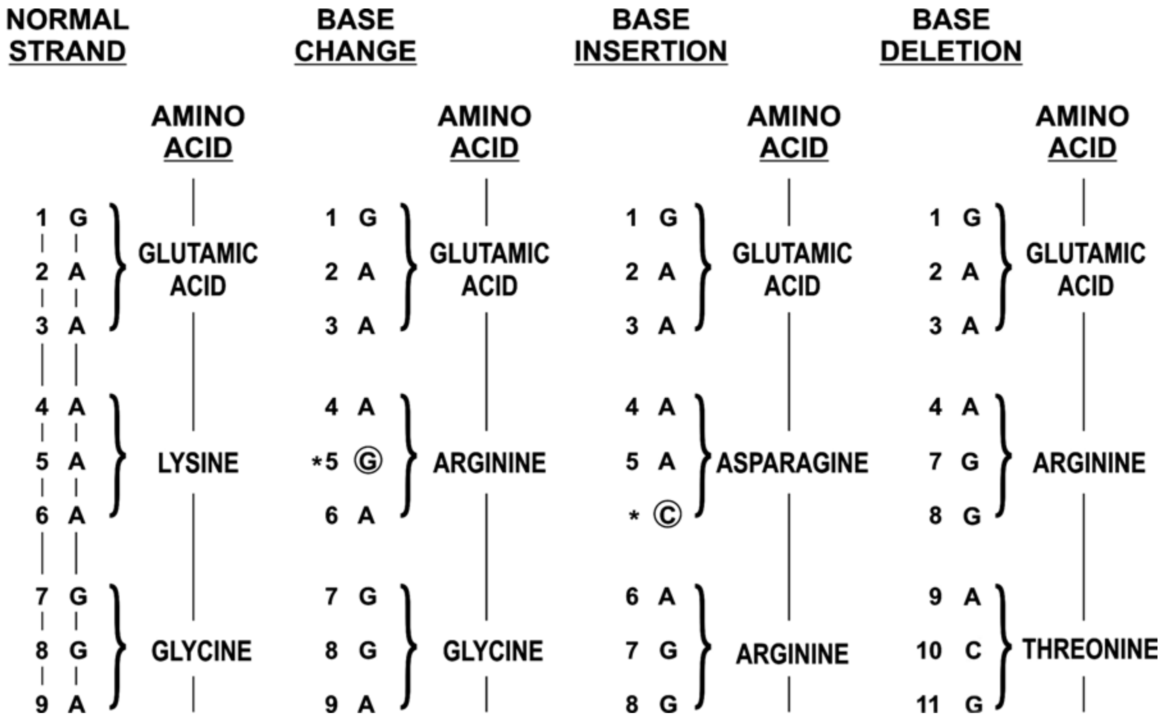

Figure 9-14. Types of mutations in the gene. One normal strand of DNA (illustrating nine bases within the strand) is shown on the left. These nine bases code for three amino acids within a longer peptide chain. A base change at position 5 from adenine to guanine changes the code for the second amino acid from lysine to arginine. The intercalation of cytosine between positions 5 and 6 changes the codes for the second and third amino acids and for every amino acid in the chain coming after them. Deleting bases 5 and 6 and closing the gap between positions 4 and 7 change the coding for the second and third amino acids and for each amino acid coming after them. Mutations may also occur by inversions (not shown).

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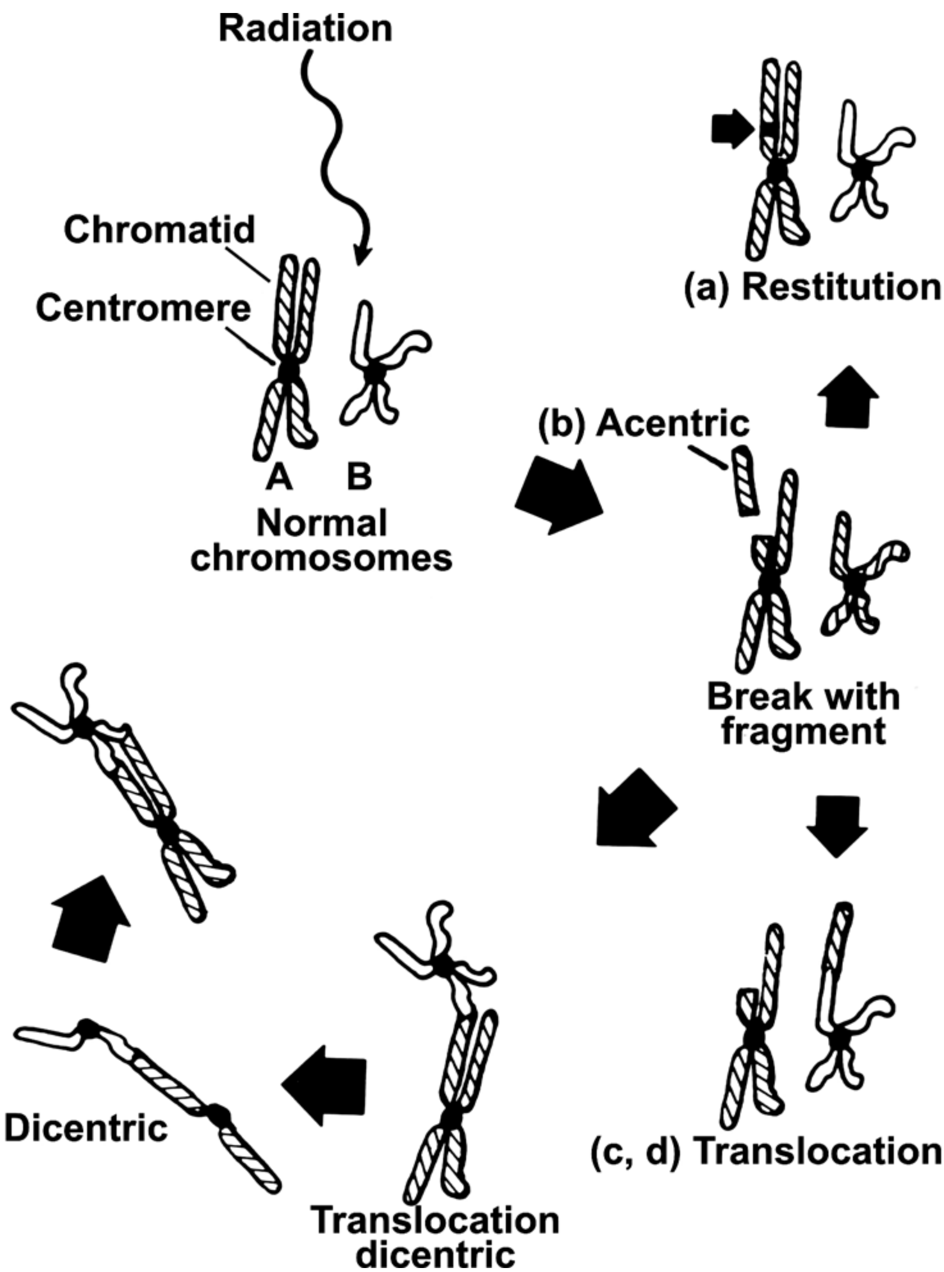

Figure 9-15. Radiation-induced chromosomal aberrations in two typical chromosomes (A and B). When a chromosome breaks, one of four events occurs: *(a)* the chromosome is restored to its original state (restitution), or the break is rejoined, with no apparent damage; *(b)* the fragment is not replaced and may be lost in subsequent divisions; *(c)* the fragment rejoins the original free end, but in a inverted position; and *(d)* the fragment may be translocated onto a nonhomologous chromosome.

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Figure 9-16. Critical periods (solid lines) for radiation-induced birth defects in mice. Studies were performed with 1-2 Gy of acute X radiation during gestation. Corresponding days for human gestation are shown at bottom. Source: Redrawn from reference 190.

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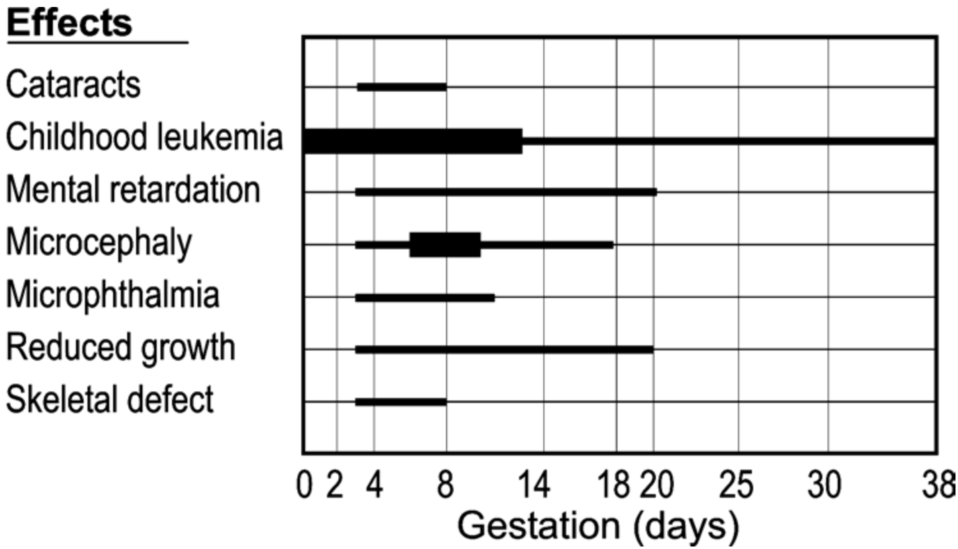

Figure 9-17. Critical periods (solid lines) for radiation-induced birth defects in humans. Children were exposed *in utero* as a result of medical radiation treatments received by their mothers. The average dose to the midline of the pelvic region ranged from 2.5 to tens of Gy. Most children had more than one anomaly, and mental retardation was usually associated with microcephaly. Source: Data are from reference 227.

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Figure 9-18. Incidence of microcephaly in Hiroshima atomic-bomb survivors irradiated *in utero.* Data are based on T65D dose estimates. Source: Redrawn from reference 232.

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TABLE 9-1
LOWER CANCER INCIDENCE RATES FROM SELECTED WORLD REGISTRIES*

Type or Site of Cancer	Connecticut Registry	Lowest Incidence Worldwide	Location of Incidence
Lung	325.8	9.0	Rural Norway
Colon	137.2	13.7	Ibada, Nigeria
Prostrate	92.3	5.3	Miyagi, Japan
Stomach	66.2	28.0	New Mexico, United States
Leukemia	57.9	40.8	Miyagi, Japan
Myeloma	15.1	1.8	Miyagi, Japan
Thyroid	12.4	3.6	Southern metro region, United Kingdom

*Per million males younger than 65 years
Source: Condensed from reference 73

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TABLE 9-2
UNITED STATES CANCER MORTALITY RATES IN 1968-1972*

Type or Site of Cancer	Number of Males	Number of Females
Lung	288.0	71.3
Colon	85.2	74.9
Prostrate	25.5	____
Leukemia	43.4	3.0
Stomach	37.5	18.2
Thyroid	1.8	2.1
Breast	1.3	174.0

* Per million males or females younger than 65 years
Source: Condensed from reference 73

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TABLE 9-3

RISK ESTIMATES FOR RADIATION-INDUCED INCIDENCE OF CANCER PER MILLION PERSONS EXPOSED PER cCy (rad) OF LOW-LET RADIATION

Type or Site of Cancer	Age at Exposure	Years at Risk After Irradiation	Absolute Risk	
			Male	Female
Absolute Risk Leukemia *	0-9	5-26	1.73	1.10
	10-19	5-26	0.85	0.54
	20-34	5-26	0.85	0.54
	35-49	5-26	1.05	0.67
	50+	5-26	1.56	0.99
Lung	10-19	10-33	0.30	0.30
	20-34	10-33	0.56	0.56
	35-49	10-33	0.86	0.86
	50+	10-33	1.20	1.20
Breast	0-9	10-35	—	3.80
	10-19	10-35	—	7.60
	20-29	10-35	—	4.90
	30-39	10-35	—	4.90
	40-49	10-35	—	1.30
	50+	10-35	—	0.80
Thyroid	0-9	10-34	1.50	5.00
	10-19	10-34	1.50	5.00
	20+	10-34	0.50	0.50
Colon	20-34	10-30	0.21	0.21
	35-49	10-30	0.34	0.34
	50+	10-30	0.89	0.89
Stomach	10-19	10-30	0.16	0.16
	20-34	10-30	0.31	0.31
	35-49	10-30	0.51	0.51
	50+	10-30	1.34	1.34
Liver	20+	10-30	0.28	0.28

* Except chronic lymphocytic leukemia
Source: Condensed from reference 11, Table VI-1-A

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TABLE 9-4
SOURCES OF DATA ON RADIATION EXPOSURE TO HUMANS

Atomic-Bomb Detonation Exposures	
	Survivors
	Offspring of survivors
Medical Exposures	
	Treatment of tinea capitis
	X-ray treatment of ankylosing spondylitis
	Prenatal diagnostic X rays
	X-ray therapy for enlarged thymus glands
	Flouroscopy (treatment for tuberculosis)
	Thorotrast treatment
Occupational Exposures	
	Radium dial painters (1920s)
	Uranium miners and millers
	Nuclear dockyard workers
	Nuclear-materials enrichment and processing workers
	Participants in nuclear weapons tests
	Construction workers
	Industrial photography workers
	Radioisotope production workers
	Reactor personnel
	Civil aviation and astronautic personnel
	Phosphate fertilizer industry workers
	Scientific researchers
	Diagnostic and therapeutic radiation medical personnel
Epidemiological Comparisons of Areas with High-Background Radiation	

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TABLE 9-5

LEUKEMIA STATISTICS FOR POPULATIONS EXPOSED TO RADIATION

Population	Average Exposure (Gy)	Follow-up Period (years)	Mean Latency To Death (years)	Number of Persons Exposed	Leukemia Cases Observed*
Atomic-bomb Survivors	0.27	27	13.7	82,000	84 (21)
Ankylosing Spondylitis Patients	3.21	20	6.6	14,109	31 (6.5)
Pelvic Irradiation Patients	1.34	19	12.4	2,068	7 (2.3)
Marshall Island Residents	0.60	28	—	240	1 (—)
Thorotrast Patients (26 ml average)	3.50	27	—	4,594	60 (6)

*Numbers in parenthesis are predicted cases of leukemia

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TABLE 9-6
INCIDENCE OF SELECTED GENETIC DISORDERS

Disorder	Incidence per 10,000 Live Births
Autosomal Dominant	
Huntington's chorea	5.0
Osteogenesis imperfecta	0.4
Marfan's syndrome	0.4
Familial hypercholesterolemia	20.0
Autosomal Recessive	
Cystic fibrosis	5.0
Phenylketonuria	1.0
Neurogenic muscular distrophy	1.0
Sex-Linked Recessive	
Duchenne's muscular dystrophy	2.0
Hemophilia	1.0
Chromosomal Disorders	
Down's syndrome (trisomy 21)	12.0
Edward's syndrome (trisomy 18)	1.0
Klinefelter's syndrome (XXY)	5.0

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TABLE 9-7
CONTRIBUTORS TO GENETICALLY SIGNIFICANT DOSES

Source		Mrem per Year
Natural		82.0
Man-made		40.0
Selective Man-made Contributors		
Medical	20.0	
Nuclear power	<1.0	
Consumer products	4.5	
Weapons testing or fallout	4.5	
Military occupational applications	<0.004	
Total		122.0

Source: Data from reference 7

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TABLE 9-8
BEIR III ESTIMATES OF INCIDENCE OF GENETIC DAMAGE*

Genetic Disorder	Current Incidence in Liveborn Offspring (per million)	Increased Incidence in Liveborn Offspring** (per million)	
		First Generation	Equilibrium
Autosomal dominant and X-linked	10,000	5-65	40-200
Irregularly inherited	90,000	5-65	20-900
Recessive	1,100	5	<10
Chromosomal aberrations	6,000	<10	<10
Total	107,100	5-65	60-1,100

* Committee on Biological Effects of Ionizing Radiation of the National Academy of Sciences
** When every individual in preceeding generation receives 1 extra rem
Source: Data from reference 7

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TABLE 9-9
ESTIMATED EFFECT OF 1 Gy BY DOUBLING DOSE METHOD OF UNSCEAR*

Genetic Disorder	Current Incidence in Liveborn Offspring (per million)	Increased Incidence in Liveborn Offspring (per million)	
		First Generation	Equilibrium
Autosomal dominant and X-linked	10,000	1,500	10,000
Irregularly inherited	90,000	450	4,500
Recessive	2,500	slight	slow
Chromosomal Diseases			
Structural	400	240	400
Numerical	3,000	small	small
Total	105,900	2,190	14,900

* United Nations Scientific Committee on Effects of Atomic Radiation
Source: Data from reference 8

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TABLE 9-10

ESTIMATED INCIDENCE OF HUMAN GENETIC DAMAGE PER Gy*

Genetic Damage	Spermatogonia	Oocytes
Dominant mutations	16-400	0-180
Balanced reciprocal translocations	220-8,750	0-875
Unbalanced translocations	440-17,500	0-5,250
X-chromosome loss	negligible	0-500

* Unbalanced translocations of chromosome fragments
Source: Data from reference 8

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TABLE 9-11
UNITED STATES NUCLEAR REGULATORY COMMISSION GUIDE FOR PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION

Body Part	Exposure (rem per calendar quarter)
Whole body	1.25
Skin of whole body	7.50
Head and trunk	1.25
Hands and forearm	18.75
Feet and ankles	18.75
Bone marrow and spleen	1.25
Lens	1.25
Gonads	1.25

Source: Data modified from reference 123

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TABLE 9-12
PENALTY TABLE OF RISK ESTIMATES FOR CONTINUOUS RADIATION EXPOSURE

Persons Requiring Medical Treatment	Maximum Cancer Deaths**	Accumulated Radiation Dose* (Sv) in any period of: One Week		One Month		Four Months	
		Total	Daily	Total	Daily	Total	Daily
None	18.0	1.5	0.21	2.0	0.066	3.0	0.025
Some (5% deaths)	28.5***	2.5	0.35	3.5	0.12	5.0	0.16
Most (50% deaths)	27.0†	4.5	0.64	6.0	0.20	—	—

* RBE of neutrons increases with decreasing dose rate
** Per batallion (1,000 soldiers) over a lifetime:
16%-20% leukemia (minimal latency 3-5 years)
Remainder will be solid tumors (minimal latency 10 years)
*** Based on calculations of 95% survivors using BEIR III estimates
† Based on calculations of 50% survivors using BEIR III estimates
Source: Based on NCRP Penalty Table, reference 54

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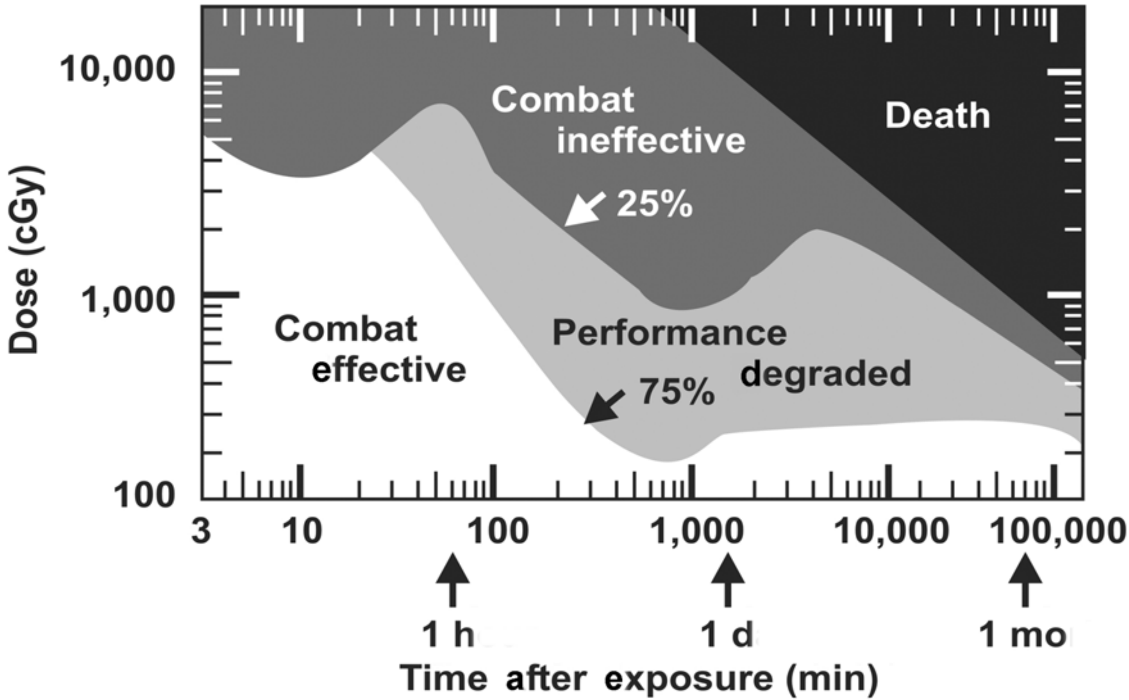

Figure 10-2. Expected response to radiation for physically demanding tasks.

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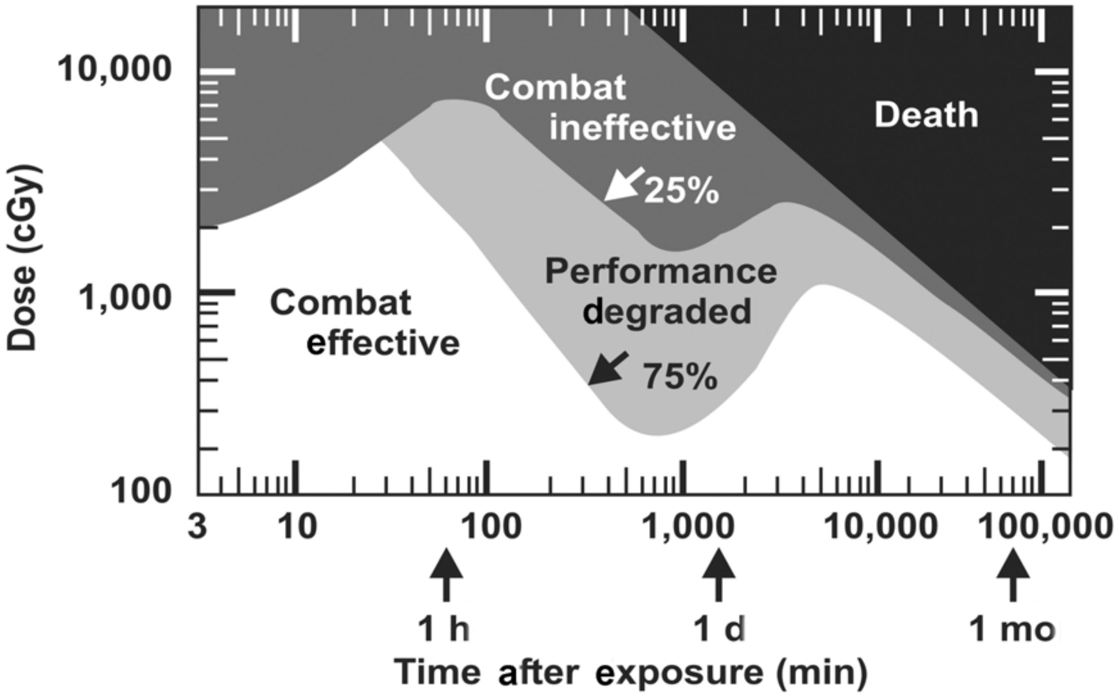

Figure 10-3. Expected response to radiation for physically undemanding tasks.

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TABLE 10-1
CHARACTERISTICS OF NUCLEAR RADIATIONS

Name	Relative Mass	Electric Charge	Emitted by	Range in Air	Tissue Penetration	Radiation stopped by
Alpha	7,300	+2	Unfissioned uranium and plutonium	5 cm	First layer of skin	Clothing Paper
Beta	1	-1	Fission products	12 m	Several layers of skin	Clothing
Gamma	0	0	Fission products	100 m	Total body	Several feet of concrete or earth
Neutron	1,830	0	Emitted only during fission	100 m	Total body	Several feet of concrete or earth

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TABLE 10-2

RADIATION EXPOSURE STATUS (RES) CATEGORY SYSTEM

RES	Dose (cGy)	Casualties (%)	Nuisance symptoms (%)	Risk
0	0	0	0	None
1	0-70	1.0	2.5	Negligible
2	70-150	2.5	5.0	Moderate
3	150+	5.0	—	Severe

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TABLE 10-3
THE 7:10 RULE FOR RESIDUAL RADIATION DECAY

Time after Detonation (in hours)	Amount of Radiation Remaining	Dose Rate Decay (cGy/hour)
1	—	1,000
7	1/10	100
49	1/100	10
343	1/1,000	1

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TABLE 11-5

PRIMATE SURVIVAL FOLLOWING 8 Gy OF COBALT-60 IRRADIATION

Category	No Supportive Therapy	Supportive Therapy Only	Supportive Therapy (allogeneic bone-marrow transplant)*	Partial Shielding**
Survivors	0	0	5	4
Total primates	4	4	5	4
Mean survival time in days	12.5	16.3	>30.0	>30.0

* Antibiotics, fluids, platelets

** Less than 1 % surviving stem cells

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